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Peat as a soil amendment for tailing sand reclamation

by

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A THESIS

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled Peat as a soil amendment for tailing sand reclamation.

submitted by Robert John Logan

in partial fulfilment of the requirements for the degree of Master of Science

DEDICATION

To my father, N.J. Logan, in appreciation
of the opportunity and encouragement
given to me.

ABSTRACT

Tailing sand reclamation is a major consideration in the surface mining of the Alberta Oil Sands. Vast amounts of the waste sands are produced and cover large land areas. The tailing sand has poor moisture conservation properties, is highly erodible and has a low fertility. Local climatic conditions, particularly moisture deficiencies, as well as topographic considerations may also limit the reclamation potential. Utilization of peat, a material which is abundant in the mining area, as a soil amendment is studied as a step towards stabilizing and revegetating the tailing sand. The literature shows that peat properties vary with degree of decomposition and classification systems have been developed on this basis. The effects of the type of peat and method of application on the tailing sand reclamation were examined in laboratory studies where basic soil properties were determined, in a greenhouse growth study where natural yields and responses to fertilization and liming were compared, and in a field runoff plot study where moisture conservation properties, soil erodibility and fertility and plant yield characteristics were measured.

Increased infiltration and available moisture storage capacity were obtained with peat amendments. Mesic peat, when mixed into the tailing sand, produced the greatest increase in available moisture storage. It was estimated that approximately 25 cm of mesic peat may be required to reduce moisture limitations to growth. The infiltration rate of tailing sand appears related to the degree of

water repellancy and residual hydrocarbons are suggested as the cause. This repellancy, the resulting low infiltration rate and the loose structure of the tailing sand combined to produce soil losses of 50 tonnes/ha from the runoff plot over two months. Application of a peat mulch eliminated soil losses. Soil losses where peat was mixed into the tailing sand were small, however runoff losses of water remained high. This suggests slowed runoff velocities and reduced splash erosion.

Results indicated that levels of available nutrients were low in mesic and fibric peats although considerable amounts of total nutrients may be present, particularly in mesic peat. Peat additions alone did not significantly increase plant yields on tailing sand and fertilization was necessary. Addition of lime was also required with acidic peat. With correct management, yields in the tailing sand-peat mixtures examined were approximately three times the best attained on un-amended tailing sand. The mesic peat required fewer inputs to obtain this result and had other soil fertility benefits.

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1.0 INTRODUCTION

Extraction of oil from the Alberta Oil Sands by surface mining operations produces large quantities, literally mountains, of sand-textured tailings (hereafter referred to as tailing sand). When deposited on the land surface the tailing sand, because of its high sand-size fraction and the extraction process it has undergone creates a growth medium with low fertility, high erodibility and poor moisture conservation properties (Massey, 1972; Lesko, 1974; Berry and Klym, 1974; McCoy et al., 1976; Regier, 1976; Takyi et al., 1977). Because of apparent similarities in texture, there is a tendency in reclamation planning to compare reclaimed tailing sand areas to the jack pine (Pinus banksiana) communities (Wheeler and Vaartnou, 1973) which have developed on fluvial sand deposits in the Oil Sands region. However, there is very little data on which to base this comparison.

To attain such reclamation objectives as erosion control and self-sustaining vegetative cover (Klym and Berry, 1976) the addition of soil amendments to the tailing sand has been suggested (Massey, 1972; McCoy et al., 1976; Regier, 1976). The use of on-site materials as soil amendments is a logical and practical choice. Surface mining operations require that overburden material (that is, the material over-lying the oil sand deposit) be removed and deposited out of the immediate mining area. These material handling operations provide an opportunity to separate out those materials which may be suitable for use as soil amendments.

Preliminary studies have indicated that mineral and organic overburden materials are found in the Oil Sands mining area (Lindsay et al., 1962; Regier, 1976). In a study of the Syncrude lease No. 17, Regier (1976) found the overburden consisted largely of coarse-textured material while finer material appeared to occur in localized, shallow deposits. The coarse material, having properties similar to the tailing sand, would be of limited use in reclamation. However, Regier (1976) concluded that the finer materials, particularly heavy clay, although limited in extent could be very useful as an amendment for tailing sand. There are also some disadvantages with this type of material in terms of erodibility (Regier, 1976) and possibly chemical properties such as salt or oil content (Takyi et al., 1977) and ease of application.

The other major component of the overburden and possible soil amendment is peat. Peat is also referred to as muskeg, although the latter term applies more correctly to the soil as a landform rather than the material (Clayton et al., 1977). Extensive deposits of peat are found in the Oil Sands area. Lindsay et al., (1962) found organic soils over 80 percent of the land in the vicinity of the current mining operations. Regier (1976) reported that peat occurred to a depth of 1 m over much of the Syncrude lease No. 17. The idea of utilizing peat as a soil amendment is not new. Over forty years ago Feustel and Byers (1936) commented that:

> "The use of peat as a source of organic matter for improving the physical condition of mineral soil is becoming increasingly important."

Currently, Great Canadian Oil Sands (GCOS) Ltd., the only operating

extraction plant in the Oil Sands, is using peat in its reclamation program. However, the need for more information on peat utilization in tailing sand reclamation has been expressed (Berry and Klym, 1974; Klym and Berry, 1976).

This study was designed to determine the effects of peat amendments towards increasing the reclamation potential of tailing sand. The influence of peat amendments on moisture conservation, soil erodibility and soil fertility and plant growth was examined. Because of the large variability in the properties of peats, different types of peat were studied as well as the method of peat application. Only the immediate effects of peat addition to tailing sand are examined, although possible long-term effects are also discussed.

A review of literature on peat classification, characteristics and use as a soil amendment was done with the objective of becoming familiar with and understanding peat properties. Laboratory analyses and experiments were conducted to determine basic soil properties. A greenhouse plant growth experiment was used to establish the fertility levels of the various materials and the effects of fertilizer and lime application on them. Field studies, mainly utilizing a runoff plot established on the tailing sand dyke at the GCOS, Ltd. site north of Fort McMurray, were conducted to examine peat effects on erosion, moisture conservation and plant growth under field conditions.

2.0 LITERATURE REVIEW

2.1.0 Introduction

Because of its nature and local availability peat has been recommended and is used for tailings sand revegetation programs by companies operating in the Oil Sands. However, relatively little scientific information is available on peat and its application to tailing sand reclamation in the Oil Sands, although much is now being gathered under the Alberta Oil Sands Environmental Research Program (AOSERP).

This review is of literature important to the understanding of peat and the influence peat amendments can have on mineral soil. Much of the literature has been drawn from agriculturally oriented sources, making it very applicable to practical reclamation knowledge.

The review has been divided into four sections: firstly, a review of types of peat and various classification systems based on their properties; secondly, the important physical properties of peats are reviewed; thirdly, the important chemical and biological or fertility characteristics of peats are reviewed; and finally, a review of papers on the use of peat as an amendment to mineral soils.

The great variety of peat has made classification difficult, but systems have been derived and are reviewed because they point out the major types and distinguishing features of peats. The review of the important physical and chemical aspects points out some of the variations among peats, while the literature on peat-

soil mixtures indicates the type of effects which have resulted and might be expected from such soil amendments.

A number of papers referred to in this review are found collectively in the Proceedings of the Third International Peat Congress (Lafleur and Butler, 1968), an excellent source of information on peat. A second important source of peat information, specific to the Alberta Oil Sands area, is being developed by members of the Research Council of Alberta and the Soil Science Department of the University of Alberta under projects VE5-1 and VE5-2 of the Vegetation Committee of the AOSERP (Lindsay et al., 1976; McGill et al., 1976).

2.2.0 Types and Classification of Peat

The effects of peat amendments to tailing sand will likely depend greatly on the properties: biological, chemical and physical of the specific peat. Because of wide variations in properties, classification systems have been developed grouping materials of similar properties.

In Canada, soils developed from deposits that are saturated most of the year, contain more than 30 percent organic matter and are over 40 cm deep are classed according to the System of Soil Classification for Canada (Can. Dept. of Agric., 1974) as Organic soils. These soils fit into one of three great groups: Fibrisol, Mesisol or Humisol, of the organic order depending on the fiber content of the dominant tier. The most important characterizing and

differentiating features are the amount of fiber and the durability of the fiber as measured by destruction on rubbing. The fiber content is that portion by volume of fiber retained on a 100 mesh (0.15 mm) sieve. A fibric material has an unrubbed fiber content of greater than 2/3 by volume and a rubbed fiber content greater than 4/10 by volume. Mesic material has a rubbed fiber content of more than 1/10 if the unrubbed fiber content is between 1/3 and 2/3 by volume. A humic material has a rubbed fiber content of less than 1/10 the volume. Further characterization considers other morphological features such as layer thickness, colour, mineral content and chemical properties such as pH in calcium chloride, pyrophosphate solubility, as well as botanical origin of the material.

The definition (Can. Dept. of Agric., 1976) of peat is:

> "Unconsolidated soil material consisting largely of undecomposed, or only slightly decomposed, organic matter."

Therefore, fibric and mesic materials may classify as peat while humic materials would be too decomposed to meet this definition. In this review however, all three organic materials are examined and referred to as peat. The term "muskeg" is often used in reference to peat although muskeg refers to the material as a landform (Clayton et al., 1977).

Farnham and Finney (1965) reviewed literature on organic soils to that time, particularly systems of classification. They found that organic deposits were classed on criteria such as topographic geography, surface vegetation, chemical properties, botanical origin, morphology and genetic processes. Their conclusion was that

all systems had ambiguous terminology, lacked definition of terms and were not very mappable. Farnham and Finney (1965) went on to propose a system of their own where fiber content (here, the portion by weight of fiber larger than 0.1 mm) was used as a criterion for classification. Peat with less than 1/3 fiber content was designated Sapric (most decomposed), from 1/3 to 2/3 fiber content was the Hemic (intermediate) stage and peat with over 2/3 fiber content was classed as Fibric (relatively undecomposed).

Classification systems also exist for "commercial" peat (that is, peat that has been mined and is sold for horticultural use). Farnham (1968) reviewed the commercial peat standards and regulations for several countries. Generally, commercial classification is based on (1) botanical origin of the peat forming plant and (2) the degree of decomposition the plant material has undergone. The latter has been measured or expressed according to numerous parameters: fiber content, amount of colloidal plant residue, colour, elasticity, and volume weight (or bulk density). Four classes of commercial peat are generally recognized: (1) *Sphagnum* moss peat, (2) other moss peat, (3) reed-sedge peat and (4) other peat (humus or muck). In Canada, use is made of the U.S. commercial peat system which recognizes the four material types mentioned above (Alta. Dept. of Industry and Tourism, 1968). This system however, uses somewhat ambiguous terms and a new system was proposed by the American Society for Testing and Materials (Farnham, 1968). Under this new classification, fiber content is defined as plant material retained on a 100 mesh screen (0.15 mm) and oven-dry (105 C) weight

is used for all percentages. Botanical origin, organic matter content and fiber content are used as the basis for classification.

Classification of peat on the basis of (1) degree of decomposition, (2) botanical origin and (3) chemistry (in particular pH and calcium content), was suggested by Puustjarvi (seminar, 1975).

In Alberta, Walker (1934) described peats as generally light coloured, raw and undecomposed, consisting of from 2 to 3 feet of mossy material which has accumulated due to cool temperatures and acid conditions retarding microbial decomposition of organic matter. Vast areas of the province are covered with peat deposits although some confusion exists as to just how much. The soil group map of Alberta (Govt. and Univ. of Alberta, 1969) shows 16 million hectares of Organic soils while the Soils Branch, Alberta Department of Agriculture (1971) estimates there are about 10 million hectares of peat, most in northern Alberta.

To date, peat soils in Alberta have been mapped as either the Eaglesham series (sedge peats) or the Kenzie series (moss peats). Some peats however are mixtures of the two types, and within the moss peats, most are derived from the genus _Sphagnum_ although feather mosses (_Hypnum_) are also common (Alta. Dept. of Agric., 1971).

Exploratory soil surveys of northern Alberta (Lindsay et al., 1962) found widespread occurrence of Organic soils in the area consisting of (1) fine-textured fibrous sedge peat and (2) coarse-textured _Sphagnum_ moss peat which was associated with the black spruce (_Picea marianna_) - labrador tea (_Lendum groenlandicum_) bogs and muskeg. In the immediate vicinity of the mining area in the

Oil Sands (Area V of map sheet 74-E; Lindsay et al., 1962) Organic soils cover 80 percent of the land area. A more detailed soil survey of the Oil Sands area is presently being conducted by the Soils Branch, Alberta Research Council.

2.3.0 Physical Characteristics of Peat

The physical characteristics of peat are often considered its most prominent and important properties. Physical properties have been found to vary greatly with the degree of decomposition of the peat material and are often, as suggested previously, used as measures of the degree of decomposition for classification purposes.

Buckman and Brady (1971) list important general characteristics of peat soils as: colour, bulk density, water-holding capacity and structure. They generalize that colour darkens as decomposition advances and humic substances are produced; that bulk densities are very low relative to mineral soils; that the total water holding capacity is greater than that of mineral soils; and that the structure is open and porous. Boelter (1968) lists water retention, water yield or storage co-efficient (a characteristic used in bog hydrology as a measure of the amount of water removed from a peat deposit when the water table is lowered) and hydraulic conductivity as the important physical properties and as Boelter (1968) states in summarizing the important physical properties of peat:

> "Knowing the degree of decomposition as measured by bulk density or fiber content

will provide...significant information about physical and hydrological characteristics of organic soils."

2.3.1 Fiber Content, Bulk Density and Degree of Decomposition

Peat forms from plant materials which initially have a high fiber content. The amount of fiber larger than a given size decreases as the material is broken down through microbial decomposition. Therefore fiber content is often used as a criterion for peat classification as discussed previously and as a measure of the degree of decomposition (Boelter, 1968; Can. Dept. of Agric., 1974). Fiber content is measured by different methods, some of which were discussed earlier.

The relationship between fiber content and water retention in peats was investigated by Boelter (1968, 1969). Using the classification system of Farnham and Finney (1965), the percent by weight of fiber greater than 0.1 mm was related to volumetric water content at several soil suctions. At saturation, the amount of water held increased with increasing fiber content to nearly 100 percent for a Fibric peat. At 5 millibars suction however, the amount of water held fell off sharply in peat with 2/3 or more fiber content. This reflects the low tension with which most of the water in fibric peats is held. At 15 bar suction, the amount of water held decreased with increasing fiber content. Therefore, a sapric (humic) peat holds less water by volume at saturation than a hemic (mesic) or fibric peat, but retains more water at 15 bar suction. Because of this

rapid drainage of the fibric peat material, the more decomposed peat should have a greater amount of plant available moisture.

Puustjarvi (1968) found that the amount of particles less than 1.0 mm in size was an important peat structural characteristic influencing air and water capacities of the material. He screened peats and measured air and water capacities, pore volume and weight per volume of the various particle-size fractions. Results (Table 1)

Table 1. The influence of peat structure as determined by particle-size on water and air capacities. From Puustjarvi, 1968.

Particle-size fraction (mm)	Weight per volume (g/l)	Pore volume (%)	Water capacity (%)	Air capacity (%)
Less than 1	62	96	83	12
1 - 2	52	96	70	27
2 - 4	56	96	64	32
4 - 8	58	96	60	36
8 - 20	57	96	58	38

showed that air capacity was greatly reduced and water capacity greatly increased in the less than 1 mm size fraction.

Bulk density is another important characteristic of peats. Boelter (1968) suggested it can be used as a measure of decomposition because as decomposition progresses, particle sizes become smaller increasing the weight per unit volume. However, caution is necessary since bulk density of peat also varies considerably with moisture

content, degree of compactness and nature of the colloidal particles as discussed by Puustjarvi (1968). This variability is likely the reason bulk density is not used as a criterion in classification systems. Typical values reported for peats range from 0.04 g/cc for undecomposed Sphagnum moss (Boelter, 1968; Farnham, 1968) to 0.25 g/cc for a commercial peat humus (Farnham, 1968) and 0.26 g/cc for well-decomposed peat (Boelter, 1968). Samples taken from a Terric Mesic Fibrisol in the Oil Sands area included 0.05 g/cc in the fibric layer and 0.07 g/cc in the mesic layer, while an average sample from a Hydric Mesisol had a bulk density of 0.02 g/cc (McGill et al., 1976). These figures show that bulk density varies greatly within and between peat deposits.

The relationship between bulk density and volumetric moisture content at various soil suctions was investigated by Boelter (1968). At saturation, as bulk density decreased, water content increased to nearly 100 percent at bulk densities under 0.05 g/cc. At 5 millibar suction the amount of water held by low density peat dropped off sharply, while at 15 bar suction, moisture content increased with increasing density. The relationships here are very similar to those found when relating fiber content to water content, indicating that fiber content and bulk density are closely related. That is, fibric peat has a low bulk density while humic peat has higher bulk densities. This can be taken a step further to generalize that peats having low bulk densities and high fiber content are relatively undecomposed while peats having high bulk densities and low fiber content are relatively decomposed.

2.3.2 Water Holding Capacity and Water Retention Characteristics

The water holding capacity of peat is often considered its most important property, although a certain amount of confusion exists about this characteristic. Many studies have reported water content on an ovendried weight basis, which, due to the low bulk density of peat materials often results in large, misleading values. Several authors have discussed the importance of using volumetric expression of water content with peats, most notably Boelter and Blake (1964) but also Buckman and Brady (1971), Farnham (1968), Boelter (1968) and Puustjarvi and Rotia (1971).

It should also be remembered that the water holding capacity of a peat refers to the water content at saturation (that is, the maximum water holding capacity), which in peat is often very high. Boelter (1966) suggests that all peats regardless of plant source or degree of decomposition contain over 80 percent (by volume) water at saturation. In the case of undecomposed moss peat this value approaches 100 percent. The actual amount of water available to plants is very different and is determined by the water retention characteristics of the material.

Water retention characteristics of peats are related to degree of decomposition which influences particle-size distribution, structure and porosity (Boelter, 1968; Irwin, 1968). The volumetric water content of peats at saturation is 2 to 3 times that of mineral soils (Feustel and Byers, 1936). Boelter (1968) found that saturated water content ranged from nearly 100 percent by volume for a fibric

peat to 80 percent for a sapric (humic) peat, indicating that total porosity decreased with increasing decomposition. There are large differences between peats in water retention at potentials only slightly greater than 0 bar due to differences in pore-size distribution. The work by Boelter (1968) (reviewed in connection with fiber content and bulk density) presented clearly these differences through the use of moisture retention characteristics curves.

The amount of water available to plants is generally considered to be that portion held between 0.33 and 15 bar soil tension (Black, 1968; Buckman and Brady, 1971). These tensions have been used to describe available water characteristics of peats (Irwin, 1968). From the retention curves presented by Boelter (1968) it is apparent that the more decomposed peats have a larger volume of available water than do the relatively undecomposed peats. Differences in pore-size distribution are again the cause. Although the decomposed peats retain more water at 15 bars soil tension, these peats drain more slowly at low suctions than do fibrous peats making the difference between the upper and lower limits of available moisture greater in the decomposed peat. Allison (1973) used the data of Feustel and Byers (1936) to compare available moisture between peats and concluded that water absorbed by fibrous peat was relatively available to plants. However, Allison (1973) calculated available water using the water content at saturation as the upper limit of availability, rather than the moisture equivalent values given by Feustel and Byers. This conclusion is therefore misleading because the large amount of water held between saturation and

moisture equivalent water content is unavailable to plants due to gravitational drainage. Table 2 presents data adapted from Feustel and Byers (1936) to show the available water held by different materials as the difference between water contents at the moisture equivalent and wilting point. The data on sand-peat mixes will be discussed later. Of the peats, the fibrous moss peat contained the least amount of available water. (It is interesting to note that this amount was greater than that held by the loamy fine sand.) The more decomposed peats had quantities of available water slightly under that of the clay loam soil.

Drying affects the water retention characteristics of peats. Puustjarvi (1968) attributed this to colloidal particles shrinking on drying and only very slowly regaining their original volume upon being rewetted. Most humic acids in peat are irreversible colloids (Puustjarvi, 1968). Differences in the colloidal nature of peats result in some peats (such as fibrous Sphagnum moss) being more readily rewetted than others. Puustjarvi (1968) concluded that the hysteresis effect common to mineral soils occurs to a varying and generally greater extent in peat. Boelter (1964) studied the effects of drying and disturbance on water retention in peats and found that dried and disturbed peats generally retained less water at a given tension. Boelter (1964) suggests that after drying the cellular pores in peat can not reabsorb as much water. He also found that drying tends to shift pore-size distribution towards smaller sizes thereby increasing the moisture retained at higher tensions. Boelter's (1964) data show that drying an undecomposed Sphagnum peat

Table 2. Moisture equivalent, wilting point and available water content in various peats, mineral soils and peat-soil mixes (1:1 by volume). Adapted from Feustel and Byers, 1936.

Material	Moisture equivalent water content (g/100cc)	Wilting point water content (g/100cc)	Available moisture (g/100cc)
Moss (fibric)	16	8.0	8.0
Sedge (mesic)	27	15.0	12.0
Reed (humic)	38	24.0	14.0
Loamy fine sand (LfS)	8.8	2.8	6.0
Coarse sand (cS)	2	0.8	1.2
Clay (C)	22	7.7	14.3
LfS + moss	12	4.8	7.2
LfS + sedge	19	11.0	8.0
LfS + reed	22	14.0	8.0
cS + moss	9.5	3.9	5.6
cS + reed	19	15.0	4.0
C + moss	18	8.5	9.5
C + sedge	24	13.0	11.0
C + reed	28	15.0	13.0

reduced its available moisture storage capacity from 7.5 percent to 4.4 percent (by volume).

The measurement of percent "water capacity" has been used (Puustjarvi, 1968) along with air capacity and pore volume, to assess peat as a medium for plant growth and to make comparisons between peats possible. The water capacity is defined as the water content (percent by volume) of a peat sample after gravitational water has been removed (see Appendix 1 for procedure). Water capacity was shown to be affected greatly by the amount of particles under 1 mm in size, as indicated in Table 1.

2.3.3 Hydraulic Conductivity

Boelter (1965; 1968) has done extensive research on the saturated hydraulic conductivity of peats. Peats exhibit a wide range of hydraulic conductivities which were found to be related to pore-size distribution which in turn varies with degree of decomposition of the peat (Boelter, 1965). Undecomposed peat contains many large pores while more decomposed peat has a lower fiber content resulting in a greater bulk density and a shift to smaller pore sizes which are not as readily drained. Table 3 indicates the wide range in values of hydraulic conductivity found by various workers. Generally, water moves very rapidly through fibric peat but large variations are found, while more decomposed and compacted peat allows very slow water movement. Boelter (1968) attributed these differences to pore-size distribution. Irwin (1968) suggests

Table 3. Examples of the range in saturated hydraulic conductivities of peats.

Type of peat	Reference	Bulk density (g/cc)	Hydraulic conductivity (cm/h)
Fibric:			
Sphagnum moss	Boelter, 1968	0.04	137
Sphagnum moss	Boelter, 1968	0.05	3.7
Sphagnum moss	Tallis, 1973	-	13.4
Herbaceous	Boelter, 1968	0.07	46.1
Moss	McGill et al.,1976	0.05	1.6
Mesic:			
Sphagnum, wood	Boelter, 1968	0.15	0.5
Herbaceous	Boelter, 1968	0.16	0.03
Moss	McGill et al.,1976	0.09	1.3
Humic:			
Decomposed peat	Boelter, 1968	0.26	0.02
Intensely humidified, compacted	Tallis, 1973	-	0.5

\- indicates data not given.

hydraulic conductivity is related to volume, size and distribution of pores.

Hydraulic conductivity of peats can be measured in the field and in the laboratory. Boelter (1965) investigated both methods and concluded that lab measurements gave significantly higher readings, likely due to shrinkage of the peat and leakage between peat and core containers. Boelter found no significant differences between vertical and horizontal flow through peat although he reports others had found horizontal hydraulic conductivity greater.

The effect of drying of peat on hydraulic conductivity was investigated by Lindsay et al., (1976). Both air and freeze-drying were used (the latter to simulate drying under winter conditions) and it was found that both forms of drying greatly reduced the hydraulic conductivity of the peats tested (Table 4).

2.3.4 Summary

Peats exhibit a wide range in physical properties. The degree of decomposition of the organic materials has an important effect on particle-size and pore-size distribution which in turn influences the physical properties. Measurement of fiber content and to a certain extent bulk density, has been found to be closely related to the degree of decomposition. The water holding capacity and water retention characteristics of peats are important properties related to the porosity and pore-size distribution of peat.

The general relationships between degree of decomposition

and various physical properties of peats are presented in Table 5. This table summarizes the general range of values usually associated with the three classes of peat decomposition using data from Boelter (1968) and the System of Soil Classification for Canada (Can. Dept. of Agric., 1974).

Table 4. The effect of drying on the saturated hydraulic conductivity (cm/h) of peat. Adapted from Lindsay et al., 1976.

Type of peat	Treatment		
	Control	Freeze-dried	Air-dried
Fibric moss	1.58	0.46	0.76
Mesic moss	1.30	0.39	0.38
Humic sedge	1.02	0.30	0.18

Several processes can influence the physical properties of peats. Drying peats, as would result from muskeg drainage or spreading peat on the soil surface, results in changes to peat properties. Microbial activity, which is responsible for peat decomposition has a very important influence on physical properties as can be seen from the change in properties with stage of decomposition.

Table 5. Common values of important physical properties as they vary with degree of decomposition of peat. Adapted from Boelter, 1968 and Can. Dept. of Agric., 1974.

Type of peat (degree of decomposition)	Fiber content rubbed	Fiber content unrubbed	Bulk density (g/cc)	Maximum water holding capacity (% ovendry weight)	Total porosity (%)	Hydraulic conductivity (cm/h)
Fibric	> 4/10	> 2/3	< 0.1	> 850	> 90	> 6.5
Mesic	> 1/10 (1/10-4/10)	1/3-2/3 (> 2/3)	0.1-0.2	450-850	85-90	0.1-6.5
Humic	< 1/10	-	> 0.2	< 450	< 85	< 0.1

2.4.0 Fertility of Peat

The fertility of a peat is related to its organic composition and the amount and availability of plant nutrients it contains. The organic composition is determined by the peat-forming plants it is derived from and the degree of decomposition it has undergone. The organic colloids and humus which result on decomposition have important influences on fertility. The amount and availability of nutrients are related to the composition (both organic and mineral) of the material and here too, decomposition has an important influence.

Studies on peat fertility come from around the world. Most have been done in relation to the agricultural use of organic soils. An example of this is the research sparked by the development of the Grey Wooded soils in Alberta for agriculture. Organic soils are common in these areas and research was done on peat fertility in the 1930's and 1940's (Walker, 1934; Newton, 1934, 1936; Carlyle, 1937; Bentley, 1941). Research has continued on this topic as interest in the agricultural productivity of organic soils continues (Alta. Dept. of Agric., 1971). A part of this work has been related to the horticultural use of peat. This agriculturally oriented research serves as a good base for information on peat fertility as it applies to the reclamation programs in the Oil Sands area.

Literature pertaining to peat fertility is reviewed in this section under the headings of organic composition and plant

nutrients and their availability.

2.4.1 Organic Composition

Peats are formed from plant residues in various stages of decomposition and therefore consist of large amounts of organic matter. To be classed as Organic soils in Canada, peat deposits must contain 30 percent of more organic matter (Can. Dept. of Agric., 1974) although many peats contain 80 to 90 percent or more organic matter on an oven-dried weight basis. The mineral or ash content of peats depends largely on how much mineral matter has been mixed into the peat (Allison, 1973). The determination of ash content is a common procedure in peat characterization (Farnham, 1968). Allison (1973) reviewed articles on the properties of peat and presents data showing ash contents ranging from less than 2 percent for a Sphagnum peat to over 27 percent for a "woody" peat, Farnham (1968) analysed nearly 200 commercial peats and found that Sphagnum peat generally has the lowest ash content, usually under 10 percent. The other classes of peats had variable ash contents.

Peat is often considered a decay resistant material. Allison (1973) attributes this to the nature of the peat and to environmental factors. The properties of the peat-forming materials, especially quantities of decay resistant materials such as lignin and the arrangement of the constituents influence greatly the resistance of the peat to microbial decomposition. A review of literature by Allison (1973) on the organic composition of peat found that lignin

was the main constituent with varying amounts of cellulose, hemi-cellulose and "protein" compounds. Starches, fats and sugars in the peat-forming plant are removed in the initial stages of peat formation as they are more readily available energy substrates for micro-organisms.

Studies of peat in the Edmonton area (Newton, 1934; 1936) showed that cellulose contents varied from 0 to 47 percent by weight, with the larger quantities being found near the surface. Lignin, because of its higher molecular weight and lower availability to micro-organisms, was found in greater concentrations at deeper levels in the profile, indicating that degree of decomposition generally increased with depth. The cellulose in _Sphagnum_ moss was found to be highly resistant to bacterial decomposition. Puustjarvi (1970) presented data on the content and types of easily decomposable organic substances in peats and peat-forming plants stating that the quantity of these materials is the most important requirement for promoting microbial activity (Table 6). According to these figures _Sphagnum_ moss contains a large proportion of easily decomposable substances (including cellulose) and should therefore support large amounts of microbial activity. Allison (1973) presented data to show that during peat formation amounts of cellulose and hemicellulose undergo a considerable decrease while lignin and nitrogen (in proteins) quantities tend to remain constant. An exception here was a _Sphagnum_ peat, where the cellulose and hemi-cellulose appeared more resistant to microbiological attack because of structural interactions with lignin and proteins.

Environmental factors also influence the resistance of peat to decomposition. The cool, moist, acid, largely anaerobic conditions under which peat forms influence both the microbial populations and the decomposition products which result. Changes in these

Table 6. Content and types of easily decomposable organic constituents in peats and peat-forming plants. Adapted from Puustjarvi, 1970.

Material	Water soluble matter (%)	Hemi-cellulose (%)	Cellulose (%)	Total easily decomposable matter (%)
(i) Peat				
Sphagnum	7.8	18.2	16.1	42.1
Bryales	3.2	13.0	4.0	20.2
Bryales-_Carex_	2.8	12.4	0	15.2
(ii) Peat-forming plants				
Sphagnum fuscum	10.1	26.8	28.7	65.6
Sphagnum warnstorfianum	6.0	21.9	28.6	56.2
Drepanocladus (Bryales moss)	3.6	13.8	20.8	38.2

factors can change the resistance of the material to decomposition. The influence of moisture content on degree of decomposition was studied by Waksman and Purvis (1932). It was found that controlling the moisture content of peat controlled the rate of decomposition. The greatest rate of decomposition of a "low moor" peat (that is,

peat formed in a shallow lake or bog from reed, sedge, grass or tree material with water high in basic minerals, rather than from an acid, moss peat) was found to be between 50 and 80 percent of the maximum water holding capacity, with the rate falling off quickly outside this range. Aeration is related to moisture content because air occupies the voids not filled with water. Aeration can affect peat composition through its influence on the type of microorganisms that cause the decomposition and on the rate and extent of decomposition (Allison, 1973). Christensen and Cook (1970) found that aeration increased the counts of mesophilic bacteria in the top 15 cm of organic soils in Alberta. Fungi numbered between 1 and 6 million per gram in the top 25 to 30 cm but below this depth numbers dropped quickly because of anaerobic conditions.

Changes in pH and nutrients can also affect peat composition. A study by Maclean et al. (1967) found that additions of limestone, particularly at rates over 5.5 tonnes/ha, increased somewhat the humification of an acid (pH 3.7), raw, mixed sedge-Sphagnum peat. Van Dijk et al. (1968) found that liming stimulated microbial activity which led to breakdown of peat causing increased acidity and a gradual decrease in soil pH one year after liming. Lindsay et al. (1976) found that added nutrients and lime generally increased microbial respiration rates of a fibric peat while in an initially more active fen peat these amendments had effects which varied from increasing to inhibiting respiration.

Another environmental factor which can affect peat composition is temperature. Temperature has an important influence on the

types of micro-organisms found in peat. A study by Christensen and Cook (1970) of Alberta peat from the three soil great groups found largest numbers of bacteria in peat were mesophiles with slightly fewer psychorphilic bacteria and very few thermophiles. Very few bacteria were found in the lower horizons of a Fibrisol which were just above 0 C. Highest counts of bacteria and fungi were recorded when the soils were sampled in the warmest months (August and September).

It should be remembered that the environmental factors do not operate separately but have influences which are interrelated. For example, if a peat soil is drained, not only is the moisture content reduced, but aeration and temperatures are increased. These changes can have important effects on peat composition through their influence on microbial activity and decomposition.

Decomposition of the raw peat leads to production of humus, a colloidal substance, with large surface area and high cation-exchange capacity (CEC). The formation and function of humus are reviewed by Allison (1973) and discussed by Buckman and Brady (1971). On a weight basis peats appear to have high CEC values relative to mineral soils, for example 120 me/100 g for raw Sphagnum (Maclean et al., 1967) whereas a loam mineral soil may be about 20 me/100 g (Buckman and Brady, 1971). However, volumetric expression of peat properties is needed to better visualize these relationships. Lucas and Rieke (1968) compare the CEC of raw Sphagnum peat, decomposed peat and a loam mineral soil and expressed volumetrically, Sphagnum peat has the lowest CEC, at about 50 me/l; the decomposed peat has

the highest at 300 me/l; while the loam falls in between at 144 me/l. Puustjarvi (seminar, 1975) also feels that CEC should be expressed on a volume basis (me/l).

Related to the CEC of a material is its buffering capacity (Buckman and Brady, 1971). The resistance of peat to change in pH can be expected to vary with the degree of decomposition since this in turn influences the CEC of the peat.

Walker (1934) found that as with many peat properties, pH varies with depth. In his studies, pH was found to increase with increased depth. Walker reported great differences in pH both within and between peat deposits. Values can range from very strongly acid (pH 3.5) to moderately alkaline (pH 8.3) in Alberta peat (Alta. Dept. of Agric., 1971).

2.4.2 Plant Nutrients and Their Availability

Of the major plant nutrients, nitrogen and phosphorous are generally present in peat in forms that are slowly available to plants through decomposition. Their quantities vary but are usually low, as is the amount of potassium.

Total nitrogen contents of peat ranging from 0.70 to 3.70 percent (by weight) are reported by Puustjarvi (1970) who feels that N-content is the most important chemical property of peat (Puustjarvi; seminar, 1975). Lower nitrogen levels were associated with raw, *Sphagnum* peat from a dry site while a saturated sedge peat had the highest level. Table 7 presents the nitrogen content of some peats.

The low levels in the *Sphagnum* peat were theorized to result from the rapid growth of the moss and that gaseous nitrogen was the only source for this peat. In peats reported by Puustjarvi (1970) the nitrogen content increased with increased moisture. Reasons given

Table 7. Nitrogen content and C:N ratios of various peats. Adapted from Puustjarvi, 1970 and McGill et al., 1976.

Type of peat	Reference	Total nitrogen (% by weight)	C:N ratio
Fibric *Sphagnum* moss	McGill et al., 1976	0.6	74
Mesic *Sphagnum* moss	McGill et al., 1976	1.0	44
Sphagnum	Puustjarvi, 1970	1.2	37
Carex-*Sphagnum*	Puustjarvi, 1970	1.8	25
Carex	Puustjarvi, 1970	2.3	19
Bryales-Sedge	Puustjarvi, 1970	2.2	17
Mesic *Carex* fen	McGill et al., 1976	2.8	17

for this are the lack of nitrification losses in the saturated peat and the possibility of nitrogen fixing micro-organisms existing in the moister peat. Studies by Newton (1936) found that peats in Alberta generally have from 0.5 to 2.5 percent nitrogen in the surface samples and about twice as much in sub-surface samples. Walker (1934) also found that nitrogen content was highest in the more decomposed layers. With decomposition of the organic constituents of peat carbon is released as carbon dioxide while the nitrogen in organic forms is only slowly released. The result is an increased

portion of nitrogen in decomposed peat (Allison, 1973). When the total nitrogen content of two peat soils and an average Edmonton area black loam were compared on a weight per volume basis by Walker (1934) the black loam contained 0.53 percent nitrogen while a Sphagnum peat contained 0.037 percent and a "fertile", decomposed peat contained 0.86 percent total nitrogen.

The availability of nitrogen is influenced by the total nitrogen content and factors (such as the carbon to nitrogen (C:N) ratio and environmental considerations) which affect the microbial activity and therefore rate of decomposition. Puustjarvi (1970) concludes that because the carbon content of peats is quite constant either the nitrogen content or the C:N ratio can be used to study the nitrogen economy of peats. Although this may be true for some horticultural grade peats, a quick review of literature shows carbon contents of peats ranging from 35 to 65 percent by weight (Allison, 1973; McGill et al., 1976). The C:N ratio in peat is generally wide, above 20:1 (Buckman and Brady, 1971) however, it too can vary considerably (Table 7). A wide C:N ratio (that is, greater than 25:1) generally indicates the material is rather fibrous, the nitrogen content is low (less than 1.2 to 1.5 percent by weight) and the rate of decomposition is likely to be slow under given environmental conditions (Allison, 1973). This is because micro-organisms require not only an energy substrate (carbon) but also a supply of nitrogen for tissue building. Without sufficient nitrogen to go around, decomposition proceeds at a slower rate. A narrow C:N ratio (less than 25) generally indicates that decomposition may proceed at a maximum

rate under the given conditions. Both carbon and nitrogen are present in quantities which will provide microbes with substrates for energy and cell synthesis. An important implication here is that if nitrogen fertilizer is applied to peat or a peat-sand mix, the rate of peat decomposition will likely be increased due to a lowering of the C:N ratio.

Although the apparent C:N ratio of peat can be rather high, much of the organic matter is rather inert (for example, lignin) and has a much slower rate of decay (Allison, 1973). Puustjarvi (1970) reported that easily decomposable organic matter (water soluble plus cellulose plus hemicellulose) content of various peats and peat-forming plants ranged from 65 to as low as 15 percent of the total organic matter content (Table 6). Therefore, the "effective" C:N ratio can be much lower (Buckman and Brady, 1971) and the rate of decomposition could be rapid. Environmental conditions, however, also have an important effect as was discussed previously. Buckman and Brady (1971) conclude that because of the narrow C:N ratio, general purpose heterotrophic organisms using carbon for energy are not encouraged, allowing nitrification (ammonium nitrogen oxidized to nitrate) to proceed. This may occur in a drained and aerated peat (such as one under cultivation or stockpiled). However, in the natural state peat has a high moisture content and low oxygen levels which severely reduces nitrification. The bacteria responsible for nitrification are largely obligate autotrophic aerobes and will not produce nitrates without the presence of molecular oxygen (Tisdale and Nelson, 1975). Lucas and Davis (1961) reported that nitrate

release was also greatly reduced under acid conditions (pH less than 5.0) because of low microbial activity.

Available data (Christensen and Cook, 1970) suggests that the heterotrophic micro-organisms (which require carbon as their energy source are present in significant numbers to allow the ammonification of protein compounds (that is, the nitrogen is mineralized into readily available forms). However, their tests for nitrification proved negative. Puustjarvi (1970) on nitrogen mineralization concluded that the larger the amount of easily decomposable organic matter a peat contains, the more immobilization occurs relative to mineralization. This is because although ammonium-nitrogen is produced on decomposition of organic matter it is then immobilized back into organic forms by micro-organisms or absorbed by higher plants. Another possible fate would be fixation of ammonium, however Christensen and Cook (1970) tested several Alberta peats and found no such occurrence.

Thus although several authors refer to high (20 to 30 ppm) levels of nitrate-nitrogen in peat samples (Walker, 1934; Hamilton and Bernier, 1973) it should be noted that the amount can be influenced greatly by changes in aeration, moisture content and temperatures which can occur through sampling procedures or muskeg drainage and handling.

It should also be noted that peat soils brought into agricultural production frequently require high rates of fertilization (Alta. Dept. of Agric., 1971). A study of ten Organic soils (including nine mesic samples and one humic sample from sedge and

sedge-grass peats) of central interior British Columbia showed that reed canary grass responded markedly to nitrogen fertilizer (Van Ryswyk et al., 1974).

To summarize, total nitrogen content of peats varies considerably, with the decomposed peats containing amounts often higher than fertile mineral soils on a volume basis. The availability of the nitrogen to higher plants depends upon the rate of decomposition which is influenced largely by the C:N ratio and environmental factors. Drainage and handling of peat can be expected to have important effects on nitrogen content and its availability.

Phosphorus in peat occurs mainly in organic forms (Odynsky, 1934). Walker (1936) found Alberta peats to have low (0.02 to 0.12 percent by weight) and varying amounts of phosphorus. He gives the example of an acid (pH 4.3) undecomposed peat containing 0.010 percent phosphorus on a weight per volume basis while a black loam from the Edmonton area contains 0.108 percent. The amount of extractable phosphorus is also related to decomposition rate with undecomposed peats having larger amounts on a weight basis (McCoy et al., 1976). Lucas and Davis (1961) reported that phosphorus was generally most available at pH 5.5. Under more acid conditions less phosphorus was available because of interaction with soluble iron and aluminum.

Potassium was found in very low (0.01 to 0.10 percent by weight) amounts in Alberta peat (Walker, 1936). These amounts are better represented on a volume basis because the low bulk density is considered. Here, the acid, undecomposed peat referred to above had a potassium content of 0.008 percent (wt/volume or g/100 ml) while

the loam from the Edmonton area had 1.49 percent potassium by volume. Newton (1935) also reported potassium deficiencies in Alberta peats. However, McCoy et al. (1976) found 1800 ppm (135 kg/ha to a 15 cm depth) of extractable potassium in a raw Sphagnum peat. Lucas and Davis (1961) reported that in peat with a high CEC and high amounts of calcium, potassium uptake can be depressed due to mass action.

Crop responses to fertilization of peat with nitrogen, phosphorus and potassium fertilizer have been reported by many sources (Newton, 1934, 1935; Alta. Dept. of Agric., 1971; Van Ryswyk et al., 1974). This indicates that major nutrients are generally not available in large quantities in peats and peat should not be considered "fertilizer" when added to mineral soil.

Peats also contain various amounts of minor plant nutrients. Sulfur is usually present in organic forms. It is a component of proteins and remains a part of the humus on decomposition (Tisdale and Nelson, 1975). Lucas and Davis (1961) reported 0.4 percent sulfur in a high-lime peat with 0.1 percent in a raised bog. Sulfate-sulfur content was found to increase with depth, possibly due to leaching. Sulfur is generally not a growth limiting nutrient in peat (Buckman and Brady, 1971).

The calcium content of most peat is very high relative to mineral soils. Walker (1936) reports 2 to 4 percent calcium in Alberta peat, the lower horizons being the richest. Buckman and Brady (1971) suggest 2.8 percent calcium (of the dry weight) as representative for peat and 0.4 percent for mineral soils. Calcium is absorbed by the organic matter from ground water seeping through the

peat deposit (it can also be removed by drainage water which may be why peat under cultivation may require liming as mentioned by Allison (1973)). Even with high amounts of calcium peats may still be acidic because of a low percentage base saturation of the very high CEC. Several studies have been made on liming as a means of improving the productivity of peat soils. Maclean et al.(1967) found application of 6.7 tonnes/ha of limestone to a raw Sphagnum peat (pH 3.7) greatly increased potato yields while heavier applications were not as beneficial. Liming was shown to increase the humification of the peat as indicated by increased ash content, bulk density and CEC and a decrease in the C:N ratio. Van Lierop and Mackenzie (1975) found calcium carbonate applications improved vegetable yields only on organic soils with a pH less than 4.0, while calcium sulfate depressed yields significantly. Hamilton and Bernier (1973) found that the pH of a virgin Sphagnum peat increased from pH 3.2 to 3.9 following cultivation.

The magnesium content of peat is generally low, 0.3 percent by weight (Buckman and Brady, 1971). Its behaviour in regards to availability is generally much like that of calcium (Lucas and Davis, 1961).

Organic matter is a micronutrient source however these elements are firmly held by soil colloids. Their release and availability depends on decomposition of the organic matter and they are generally more soluble at low pH (Buckman and Brady, 1971). However, very acid peat can be deficient in copper and molybdenum, while liming peat above pH 5.8 was found to decrease the availability of manganese

and zinc (Lucas and Davis, 1961). Regier (1976) found adequate levels of iron and manganese in peat (pH 6.7) of the Oil Sand area, however copper and zinc were only marginally adequate. Boron is generally most available under acid conditions, however Lucas and Davis (1961) reported boron to be deficient under very acid conditions in the peats they examined.

To summarize, the fertility of peat as with the physical properties, is closely related to degree of decomposition. The organic composition of peat is altered through decomposition and this influences the C:N ratio, humus content, CEC and buffering capacity, all important characteristics in determining the level of fertility. The total nutrient content of peat is determined largely by the content of elements in the peat-forming plant, but again decomposition has an effect. Nitrogen for example is conserved as carbon is used up during decomposition, resulting in a higher nitrogen content in humic peat. The availability of nutrients is related to the total content and to the rate at which nutrients become available through decomposition. Peats under agricultural production have shown good yield responses to applied fertilizer, indicating that availability of nutrients can be a growth limiting factor. Evidence from agricultural sources indicates that changing the environment in which a peat originally exists can influence many of the fertility characteristics. Most changes (drainage, aeration, liming, fertilizing) lead to an increase in fertility as decomposition to humic forms is encouraged.

2.5.0 Peat - Mineral Soil Mixes

Most literature on the use of peat to amend or condition mineral soil consists of studies of the changes in physical properties peat can produce; few look at the effects on soil fertility.

Allison (1973) lists the main reasons for adding peat to mineral soil as:

"(1) improvement of the physical conditions (tilth)
(2) increasing the water-holding capacity
(3) as a humus and nutrient source
(4) to provide a better rooting medium"

This list suggests that alteration of physical properties would be the main benefit. Allison also generalizes that the greatest benefits of additions are obtained when peat is mixed into very sandy or high clay soils and least improvement results from addition to loam soils that already have some organic matter. The degree of the benefit also depends on the type of peat.

2.5.1 Peat as a Soil Conditioner

Lucas and Rieke (1968) found that most peat sold in the U.S. was used as a soil conditioner for horticultural uses. Peat is chosen mainly because its high chemical buffering capacity and good moisture retention were advantages it had over other materials such as vermiculite. Studies of the effects of peat additions on soil tilth have been done for many years. Walker (1934), Carlyle (1937) and Bentley (1941) reviewed most of the early studies, where it was found basically that peat was useful for improving soil physical

properties and that peat was a persistant form of organic matter. More recently, Simard (1968) studied the use of peat as an agricultural soil conditioner and found that as such, only large quantities (470 to 660 cubic meters per hectare) improved yields significantly. On the use of peat for soil conditioning Allison (1973) states that:

> "The addition of a well decomposed peat or muck to such soils at rates of one-sixth, one-third, or more by volume will go far towards making such soils, both sands and clays, nearly ideal for tillage."

The duration of any physical benefits gained by peat additions should be several years as, generally, 90 percent of the peat remains after the first season according to Allison (1973). Sowden and Atkinson (1968) studied the effect of long term annual additions of organic amendments (from seven sources) and found that only peat and muck increased the organic matter content of a clay soil and also had the greatest effect on increasing the carbon content of a sand.

2.5.2 Influence of Peat on Bulk Density

Peat additions reduce the bulk density by increasing porosity, thus improving conditions for plant rooting. Incorporation of peat into the subsoil can help root penetration through hardpans and into subsoils which lack calcium or have excessive soluble aluminum (Allison, 1973). Farnham (1968) illustrates the effect of peat additions to sand on the bulk density (Table 8). Although the

reed-sedge peat is more than three times as dense as the *Sphagnum* peat, their effects on the bulk density of the sand are similar because of the relatively greater difference in bulk density between the sand and peat.

Table 8. Bulk density (g/cc) of sand as influenced by addition of two commercial peats. From Farnham, 1968.

Percent (by volume) of peat added to sand	Type of peat: Sphagnum	Type of peat: reed-sedge
0	1.53	1.53
20	1.23	1.25
40	0.93	0.97
50	0.78	0.83
100	0.04	0.14

2.5.3 Influence of Peat on Moisture Holding Capacity

The effect of peat additions on moisture holding properties of mineral soils has received considerable attention because this is often considered to be peat's most important influence. Although studied for a long while, much confusion still exists as to what the effect of peat actually is. Part of this confusion results from expression of moisture contents on a weight basis, as has often been done in the past. Farnham (1968) describes volumetric expression of moisture content as:

> "...much more realistic than the dry weight basis and it shows the actual water content of various peat materials in their proper prospective."

When dealing with sand-peat mixtures, volumetric expression of moisture content becomes even more important because of the wide range in bulk densities. Stevenson (1974) explains that peat added to soil increases the amount of water the mixture can hold per unit weight. However, it at the same time decreases the bulk density and therefore the actual volume of water held depends on the magnitude of these two changes.

When peat is added to mineral soil in the field, the maximum amount of water which can be held is a function of the volumetric water holding capacity (the saturation capacity) of the peat-sand mix and also the total volume or depth of the mixture. This is important in terms of infiltration and water erosion prevention.

The effect on moisture holding capacities of peat additions to mineral soils was studied by Feustel and Byers (1936). Their results showed that maximum moisture holding capacity (at saturation) increased in proportion to the quantity of peat added to the soils. There were only small differences between various types of peat. Table 9 adapted from Feustel and Byers (1936), shows the effects of these peat additions on the moisture holding capacities of sands. Feustel and Byers (1936) also reported that peat additions increased the volumetric water content of a clay loam soil at saturation by slightly lesser amounts (40 to 50 percent). More recently, Stevenson (1974) compared the volumetric water content of peat-soil mixes at 0.1 bars soil tension and found similarly that the coarser soil, a

Table 9. Effects of peat additions to mineral soils on moisture holding capacity. Adapted from Feustel and Byers, 1936.

Material	Moisture req'd to saturate 100 cc of dry material (g)	Percent (by volume) increase in moisture holding capacity
Loamy fine sand (LfS)	42	-
Coarse quartz sand (cS)	39	-
Moss peat (fibric)	101	-
Sedge peat (mesic)	91	-
Reed peat (humic)	99	-
LfS + 50 % moss	73	74
LfS + 33 % moss	60	43
LfS + 20 % moss	53	26
LfS + 50 % sedge	64	52
LfS + 33 % sedge	57	36
LfS + 20 % sedge	52	24
LfS + 50 % reed	67	60
LfS + 33 % reed	59	41
LfS + 20 % reed	54	29
cS + 50 % moss	67	72
cS + 20 % moss	54	39
cS + 50 % reed	71	82
cS + 20 % reed	49	26

loamy sand, benefited the most from peat additions. A finer, silt loam experienced a decrease in volumetric water content with peat additions. The amount of water a soil holds at saturation is a measure of its total porosity, thus it must be concluded that the changes in maximum water holding capacity are due to changes in total porosity.

2.5.4 Influence of Peat on Moisture Retention and Availability

Peat additions also influence moisture retention and availability characteristics when added to soil. Feustel and Byers (1936) investigated this aspect of the water budget. They found (Table 2) that peat additions increased the amount of moisture retained at the wilting point. The increase was found to be in proportion to the amount of peat added and the type of peat added. Table 2 also presents data on the amount of available water held by the various materials as calculated by subtracting the moisture content at wilting point from the moisture content at the moisture equivalent (field capacity) level. From this table it can be seen that the effects of peat additions vary with the texture of the mineral materials. The amount of available moisture is increased by peat additions to sands while it is decreased when peat is added to the finer, clay loam. The type of peat made very little difference. Although not shown in this table, the more peat added, the greater the benefit (or in the case of finer soils, the greater the reduction in available moisture). Feustel and Byers (1936) concluded that

peat amendments were beneficial to the moisture budgets of the coarse sand and to a lesser extent the fine loamy sand. They also concluded that the more humified reed peat was more effective than the fibrous moss peat in improving the moisture budget.

Stevenson (1974) also discussed moisture retention effects of peat amendments to mineral soils. He concluded that peat additions cause a shift in pore-size distribution which determines the amount of water retained at various soil tensions. His results also showed that the benefit of peat additions varied with soil texture. Stevenson also concluded that when a commercial, raw peat was added to a loamy sand it increased volumetric water retention by shifting the pore-size distribution towards smaller diameter, less easily drained pores. Peat added to a finer, silt loam soil decreased volumetric water retention because of a shift towards larger, more rapidly drained pores. The effect on a medium-textured sandy loam was almost negligible because peat had little effect on pore-size distribution. Farnham (1968) analysed various commercial peat-sand mixes and found that at 20 cm soil tension (at which tension he suggested all water subjected to gravitational forces was removed from mixtures contained in pots) there was little difference between types of peat in the amount of water retained. However, the greater the amount of peat added to sand the greater was the amount retained. Thus, the amount of peat that is applied to a mineral soil in the field should have an important influence on the degree of moisture conserved and on erosion control.

2.5.5 Influence of Peat on Evaporation

Another important factor in moisture conservation is the effect of evaporation on the water content of soils. Evaporated water is water lost to plant use. Feustel and Byers (1936) studied this problem in relation to peat additions to various mineral soils. They found that the influence of peat on evaporation was for the most part similar on a clay loam soil and a loamy fine sand. Starting with materials in a saturated state the initial rate of evaporation from the soil was unaffected by peat addition. This represents the first or constant rate stage (Baver et al., 1972) of evaporation where the rate is controlled by the evaporative demand rather than any soil property. This stage continues roughly until the surface of the soil becomes dry. At this point the second or falling-rate phase of evaporation begins because besides environmental factors the hydraulic conductivity of the soil controls the evaporation rate. The different types and amounts of peat had various effects which Feustel and Byers (1936) attributed to corresponding differences in capillary properties as affected by the peat. In both mineral soils, fibrous moss peat increased the rate of evaporation to the greatest extent during the second stage, while the humic reed peat had the least effect. Also, the more peat added, the greater was the increase in evaporation rate. When the materials had a lower but identical initial moisture content peat additions reduced evaporation rates with the humic peat being most beneficial followed by the sedge peat and finally the moss peat. In so far as

plant available moisture was concerned the addition of the mesic sedge peat and humic reed peat to loamy fine sand were beneficial while the moss peat had a negative effect, hastening the wilting. However, with a coarse sand the moss peat was also beneficial in supplying moisture to the plants. Feustel and Byers (1936) concluded that the granular properties of the more humic peat creates an insulating effect because of the discontinuing nature of the capillary pores, while the fibric peat rapidly conveys water to the surface. Mulches are commonly used to reduce evaporation (Buckman and Brady, 1971; Allison, 1973). Allison (1973) warns that with peats the more decomposed types should not be applied to the surface as they are susceptible to wind erosion and also become difficult to rewet once dry. This results in infiltration being reduced and the potential for water erosion being increased. When mixed into the soil the peat is less likely to dry out and therefore erosion potential is decreased.

2.5.6 Influence of Peat on Soil Fertility

Studies of the influence of peat additions to mineral soil on soil fertility are less common than those on physical effects. Peat has its main influence on mineral soil fertility through its organic matter properties and to a lesser extent its nutrient content. There are also the indirect benefits through alteration of soil physical conditions which produce a better environment that encourages an improvement in fertility.

An early study in Alberta by Carlyle (1937) found that the addition of decomposed peat was more beneficial than fibrous peat in increasing micro-organism numbers and nitrate-nitrogen levels of Grey Wooded soil (Luvisols). A more recent study by Szymanowski (1968) found that large quantities (200 tonnes/ha) of peat were required to have an effect on crop yields. Sowden (1968) found that as with five other sources of organic matter, peat and muck added to a sand and a clay soil had only a slight effect on increasing nitrogenous compounds. Obviously, due to the low nutrient levels and slow rate of decay peat additions cannot be expected to increase plant available nutrient levels in a mineral soil by very much. This topic is reviewed by Allison (1973). The low nutrient content of peat was shown when initial growth chamber investigations of tailing sand reclamation recommended that a high rate of complete fertilizer be added along with peat to prepare a seedbed (Massey, 1972; Berry and Klym, 1974).

However, peat additions do increase the humus content of mineral soils and to this end, the more decomposed peats are most useful because of their high colloidal content (Allison, 1973). Sowden and Atkinson (1968) found in a long-term study that annual additions of peat and muck increased organic matter in a clay soil and carbon content in a sand while five other sources of organic matter (including straw, alfalfa, leaves and manure) did not. However, these latter sources had the greater effects on yields and nutrient uptake (Halstead and Sowden, 1968). Lucas and Rieke (1968) suggest that one of the prime reasons for the use of peat in horti-

culture is its high buffering capacity which is related to CEC. In the field situation peat added to a soil with a low CEC (such as sand) could have important influences on the ability of the soil to resist change in pH due to fertilization or atmospheric pollution. To this end, a more decomposed peat, containing a larger amount of humus, would be more advantageous than a fibric peat.

2.6.0 Conclusion

The literature reviewed contains a large amount of information about the general nature and properties of peat and of the types of effects which might be expected when peat is added to tailing sand. However, only limited research has been done on peat amendments to sand and much of this has been oriented to peat culture and horticultural uses, which often is not applicable to field conditions. Confusion also results due to the use of ambiguous terms in some of these studies.

Peats vary greatly in their properties and these differences will affect the benefit obtained when peat is added to tailing sand. Therefore, it is necessary to take an inventory of the peat resources available to a reclamation program. In the past only limited exploratory surveys and samplings had been done in the Oil Sands area (Lindsay et al., 1962; Regier, 1976). Fortunately, the present trend is to more detailed soil mapping. Peats can be inventoried or classified on the basis of many different criteria. The Canadian System of Soil Classification (Can. Dept. of Agric., 1974) can serve as a

good basis. Under this system materials are differentiated on the basis of degree of decomposition which has been shown to control many properties of peat. As well, the botanical descriptions allow materials to be differentiated and mapped in the field. This system has drawbacks when peats have been disturbed as a result of stock-piling. However, several basic analyses can reveal a large amount of information about peat.

Many important physical properties of peat are related to the degree of decomposition as measured by fiber content. This determination will allow estimation of peat properties and also of the general results which can be expected when peat is used as an amendment. Again with fertility characteristics of peat, the general characteristics can be predicted largely on the state of decomposition of the material. However, the botanical origin of the material and environmental factors can have important effects which alter the value of the material.

Thus, the effect of peat additions to tailing sand will vary greatly, depending on peat properties and also on the amount of peat added. Probably the most important role peat amendments can play in the reclamation process is in soil moisture conservation. Tailing sand has a low water holding capacity and retains little available moisture for plants. It is also very erodible by both wind and water. Peat additions can be expected to improve water infiltration due to increases in hydraulic conductivity and maximum moisture holding capacity. Greater infiltration means less runoff, particularly important on slopes. Peat additions will also retain

more of this water for plant use, with the amount varying with the type and amount of peat added. The result is increased plant growth as moisture supply becomes less limiting. Peat additions will also affect evaporation rates and variations between peats can be important here in keeping these losses to a minimum.

Peat amendments can also beneficially affect other physical properties of tailing sand. Decreasing the soil bulk density improves root penetration producing a more stable soil surface. Through these physical improvements peat contributes to the reclamation process by stabilizing the soil and improving the physical environment for plant growth.

The additions will also affect the fertility of the tailing sand. Added organic matter, especially the humus material, contributes to nutrient retention through its high cation-exchange capacity and to the buffering ability of the soil. Some nutrients are also added. These factors affect the growth of plants which in turn contributes to the stabilization of the tailing sand.

This review of the literature allows these general statements to be made. More precise information as to the degree of the benefits and differences between types and amounts of peat is what this thesis pursues.

3.0 MATERIALS

Bulk samples of materials used in laboratory and greenhouse investigations were obtained from the Fort McMurray, Alberta region. Two sand and four peat samples were selected.

A sample of tailing sand was obtained from the GCOS, Ltd. tailings dyke. The sample was taken from a depth of 1.0 to 1.3 m under a recently (within three years) seeded area. The sand had 85 percent fine sand particles, a single-grain structure and a loose consistency when moist or dry. The complete particle-size analysis, the percent loss-on-ignition and the mean particle density are given in Table 10. The reaction (pH) of the tailing sand was near neutral while electrical conductivity (EC), total nitrogen and extractable phosphorus were all low (Table 11). The CEC was very low as determined by neutral salt and ammonium acetate (pH 7.0) extract methods.

The second sand sample was obtained from a previously undisturbed Ae horizon of a Eutric Brunisol near the Mildred Lake AOSERP camp site. At the sampling site the sand appeared to have been deposited by moving water and thereafter reshaped by wind, making it a fluvial-aeolian deposit. However, for brevity it is referred to as fluvial sand throughout this thesis. The soil developed under a jack pine (Pinus banksiana) community (Wheeler and Vaartnou, 1973). Mineral soils of this general area had earlier been described as Minimal Podzols developed on lacustrine sand deposits (Lindsay et al., 1962). The fluvial sand consists of

Table 10. Particle-size analysis, textural class, percent loss-on-ignition, and mean particle density of the sand samples used in laboratory and greenhouse investigations.

Soil property	Sample	
	Tailing sand	Fluvial sand
Very coarse sand (%) (1.0 - 2.0 mm)	0	0.8
Coarse sand (%) (0.5 - 1.0 mm)	0.4	6.3
Medium sand (%) (0.25 - 0.5 mm)	3.3	41.9
Fine sand (%) (0.10 - 0.25 mm)	84.6	41.9
Very fine sand (%) (0.05 - 0.10 mm)	8.7	2.1
Silt (%) (0.002-0.05 mm)	3.0	6.0
Clay (%) (less than 0.002 mm)	0	1.0
Textural class*	fine sand	sand
Loss-on-ignition (%)	0.5	0.6
Mean particle density (g/cc)	2.64	2.64

* Canada Department of Agriculture, 1974.

Table 11. Chemical properties of sand and peat samples from the Fort McMurray area.

Soil material	pH	EC mmho/cm	Per-cent N*	Per-cent C*	C:N	Extract-able P (ppm)	Exchangeable cations** (me/100 g) Ca	Mg	Na	K	CEC*** me/100 g	me/100 cc
Tailing sand	7.2	0.5	0.01	-	-	1.5	0.48 (0.17)	0.09 (0.10)	0.11 (0.41)	0.05 (0.04)	0.7 (0.4)	1.0 (0.6)
Fluvial sand	5.8	0.3	0.01	-	-	11.4	0.62 (0.24)	0.04 (0.05)	0.05 (0.02)	0.04 (0.05)	0.8 (1.2)	1.1 (1.7)
Fibric (acid) peat	3.8	0.1	0.88	44.6	51	12.4	62 (27)	71 (8.4)	1.9 (0.84)	1.8 (0.81)	73 (263)	4 (13)
Mesic (Om) peat (Terric Mesic Fibrisol Om layer, 30 - 60 cm)	6.3	0.1	1.17	44.4	38	5.4	239 (100)	20 (27)	2.1 (0.69)	1.6 (0.46)	263 (180)	26 (18)
Fibric (Of) peat (Terric Mesic Fibrisol Of layer, 0 - 60 cm)	5.8	0.1	1.19	45.2	38	54.3	136 (67)	16 (29)	2.7 (1.4)	1.6 (1.7)	156 (138)	8 (7)
Mesic (stockpiled) peat	6.0	0.6	1.67	37.6	23	5.4	208 (95)	12 (19)	1.6 (2.9)	0.08 (0.31)	222 (162)	47 (34)

\- not determined.

* not expressed on an ash-free basis.

** in each case the upper number is the amount of cation exchangeable in neutral salt solution while the lower number in parenthesis is the amount of cation exchangeable in ammonium acetate at pH 7.0.

*** CEC determined by summation of Ca + Mg + Na + K for neutral salt extract and by displacement and determination of absorbed NH_4 for the ammonium acetate extract. Expression of CEC on a volumetric basis calculated from weight basis using bulk densities of peats in Table 13 and using 1.40 for sands.

42 percent medium sand. A total of 49 percent of the soil separates were over 0.25 mm compared to only 4 percent in the tailing sand (Table 10). The fluvial sand also had a single-grain structure and loose consistency. The pH of the sample was medium acid and EC, total nitrogen and CEC were all low as would be expected of a well-drained sand material (Table 11). Table 12 gives some chemical and physical characteristics of the soil at the sampling site.

A total of four peat samples were collected, however only two, a fibric, extremely acid (pH 3.8) Sphagnum moss peat and a sample from the mesic (Om) layer of a Terric Mesic Fibrisol, were used in most investigations (Table 11).

The fibric (acid) peat had a high fiber content, a low ash content, a bulk density of 0.05 g/cc and a high air capacity, properties expected of relatively undecomposed Sphagnum peat (Table 13). The wide difference in CEC values between summation and determination of absorbed ammonium (Table 11) suggests a high concentration of other cations, which because of the very low pH are likely mainly hydrogen ions. The sample was obtained from a disturbed, drained site on the GCOS, Ltd. lease.

The sample of mesic (Om) peat had a slightly acid reaction (Table 11) with a lower fiber content and air capacity and a higher ash content and bulk density than the fibric (acid) peat, indicative of its greater degree of decomposition. This sample was obtained from the mesic (Om) layer at a depth of 30 to 60 cm in an undisturbed black spruce (Picea marianna) muskeg community (Wheeler and Vaartnou, 1973) south of Fort McMurray, where 60 cm of organic material had

Table 12. Characteristics of the Eutric Brunisol developed on fluvial sand under a Pinus bankiana community near the AOSERP camp site at Mildred Lake, Alberta. Samples 1 and 2 were taken from the same locations and at the same time.

Depth (cm) of sample (Sample 1)	Depth (cm) of sample (Sample 2)	Bulk density (g/cc)*	pH	Mineral nitrogen NH_4-N (ppm)	Mineral nitrogen NO_3-N (ppm)
0 - 7.5		1.32 ± 0.07			
7.5 - 15.0		1.44 ± 0.03			
	0 - 15		5.8	1.9	0.2
15.0 - 22.5		1.51 ± 0.03			
22.5 - 30.0		1.52 ± 0.04			
	15 - 30		5.9	2.8	0.5
38.0 - 45.5		1.55 ± 0.02			
53.0 - 60.5		1.52 ± 0.03			
	30 - 60		5.9	2.6	0.7
	60 - 90		6.0	1.9	1.1

* mean bulk density and standard deviation based on three replications.

Table 13. Physical characterictics of the peat samples.

Material	Unrubbed fiber content (%)	Rubbed fiber content (%)	Ash content (% by weight)	Bulk density (g/cc)*	Air capacity (%)*	Water capacity (%)*	Pore volume (%)*	Real specific gravity (g/cc)
Fibric (acid) peat	88	78	3	0.05	48	49	97	1.49
Mesic (Om) peat (Terric Mesic Fibrisol Om layer, 30 - 60 cm)	72	47	21	0.10	33	62	95	1.80
Fibric (Of) peat (Terric Mesic Fibrisol Of layer 0 - 30 cm)	88	78	10	0.05	57	40	97	1.61
Mesic (stockpiled) peat	-	-	26	0.21	-	-	-	1.72

\- indicates not determined.

* by methods of Puustjarvi (1968). See Appendix 1.

accumulated over mineral materials.

The third peat sample was obtained from the surface (0 to 30 cm) fibric (Of) layer of the Terric Mesic Fibrisol from which the mesic (Om) peat was obtained. It had a medium acid reaction (Table 11) and physical characteristics similar to the fibric (acid) peat (Table 13). The extractable phosphorus content was relatively high in this sample but less than has been found in other fibric peat from the area (McCoy et al., 1976).

The last peat sample was obtained from a stockpile on the GCOS, Ltd. lease. It consisted mainly of mesic material with smaller amounts of humic, fibric and mineral materials mixed-in. Material from this stockpile was being utilized by GCOS, Ltd. for soil reclamation.

4.0 ANALYTICAL METHODS

4.1.0 Sample Preparation

The bulk sand samples were air-dried and passed through a 2 mm (10 mesh) sieve prior to storage and later use.

Bulk peat samples underwent two different preparations. A portion of each sample was air-dried, passed through a 6 mm screen and stored at room temperature. The remaining portion was screened (6 mm) while moist and stored moist at temperatures under 4 C. The moisture contents of these initial samples are given in Table 14.

Table 14. Moisture content of the various materials after initial sample preparation.

Material	Percent moisture (by weight)	
	moist	air-dried
Tailing sand	-	0.1
Fluvial sand	-	0.7
Fibric (acid) peat	330	35
Mesic (Om) peat	492	48
Fibric (Of) peat	686	-

A number of analyses and experiments required that peat be mixed with the tailing sand. All mixtures were made on a volume basis using peat to sand ratios of 1:3, 1:1 and 3:1 (or 25, 50 and 75 percent peat by volume). The required volumes of materials were

measured out and placed in pans. To ensure a homogeneous mixing it was necessary to moisten the materials, otherwise the light organic particles separated from the sand. This procedure also allowed a more uniform wetting of the sample in future experiments since both the tailing sand and air-dried peat are somewhat water repellent. The materials were mixed in the pans using spatulas until the peat was thoroughly incorporated. Mixtures which included moist peats did not require the additional water except where a high portion of tailing sand was added.

4.2.0 Physical Determinations

4.2.1 Particle-Size Analysis

The pipet procedure of Green (1976) was used to determine particle-size distribution. Samples were pretreated with hydrogen peroxide to remove organic matter. The sand fraction was separated using a sonic sifter with seive sizes of 1.0, 0.5, 0.25, 0.01 and 0.05 mm. The total clay fraction was determined by pipetting, while the silt fraction was determined as the difference between total weight (using a duplicate sample) and weight of sand plus clay. The particle-size and texture designations are those used in the System of Soil Classification for Canada (Can. Dept. of Agric., 1974).

4.2.2 Mean Particle Density

The mean particle density (or real specific gravity) of the sand samples was determined using the pycnometer method described by Blake (1965). With peat samples, the same procedure was followed, however, 100 ml volumetric flasks were used as pycnometers because of the coarse nature of the moist peat. To remove air, 20 g samples of moist peat in the flasks were immersed in a water bath (100 C) for five hours. Duplicate samples were run of both sands and peats.

4.2.3. Loss-on-Ignition and Ash Content

The method of Atkinson et al. (1958, cited in McKeague, 1976) was used to determine the percent loss-on-ignition. The ash content of peat was obtained by similar methods except that the weight of ash was expressed as a percent of the ovendry (105 C) weight of the sample.

4.2.4 Fiber Content

The volumetric unrubbed and rubbed fiber content of peat materials were determined on moist samples using the procedure outlined in the System of Soil Classification for Canada (Can. Dept. of Agric., 1974). Measurements were replicated three times.

4.2.5 Peat Standards

Water capacity, pore volume and air capacity were determined using the techniques of Puustjarvi (1968). These methods are described in Appendix 1. The bulk density of the moist peat samples used in these determinations was also calculated, using the ovendry (105 C) weight and known volume of moist peat. Duplicate samples were used.

4.2.6 Bulk Density

The bulk density of materials was obtained by determining the moist volume of the sample and the ovendry (105 C) weight of the material. For field samples, a core (7.6 cm in diameter by 7.6 cm in length) was inserted into mineral soil at various depths. With peat samples, measured volumes were cut out with a knife and then ovendried (70 C). Bulk density is calculated as the ovendry weight (in g) per unit volume (in cc) of material at field moisture content unless otherwise stated. In the lab, the bulk densities of peats were obtained from the materials used in determination of peat standards as discussed in section 4.2.5. Samples were replicated a minimum of two times.

4.2.7 Moisture Retention Characteristics and Soil Porosity

The moisture content of the soil materials was measured

at 0, 0.01, 0.06, 0.33 and 15 bar moisture tension. The moisture content at a given soil tension was obtained gravimetrically and then converted to a volumetric expression using the bulk density of the material at saturation (0 bar). The 0.33 and 15 bar moisture content were determined on disturbed samples using the pressure plate and pressure membrane extraction procedures respectively, described by Eilers (1976). Duplicate samples were used. Measurements of moisture content at 0, 0.1 and 0.06 bar moisture tensions were made using the tension table method described by Eilers (1976). Core samples were prepared by packing disturbed materials to a bulk density similar to those expected in the field. Samples were moistened before compressing (with a hydraulic press) into the cores of known volume. Measurements were made in triplicate.

The total porosity of the materials was calculated based on the water content at saturation (0 bar) and the known bulk density. The air porosity (Can. Dept. of Agric., 1976) was determined as the percent of the bulk soil volume emptied by draining the saturated cores under 60 cm (0.06 bar) of moisture tension.

Available moisture storage capacity of the soil materials was determined as the difference between 0.33 and 15 bar moisture contents. This comparison is commonly made in mineral soils (Black, 1968) and has been used on organic soils (Irwin, 1968).

4.2.8 Infiltration Rates

The rate of water intake into soil was measured in the

field using concentric rings and maintaining a constant head (Verma and Toogood, 1968; Bertrand, 1965). Metal rings were placed in the ground one week prior to measurements to allow for settling of soil disturbed on installation. An inner ring of 30 cm diameter and an outer ring of 46 cm diameter were used. Rings were 20 cm high and sunk 8 to 10 cm into the soil. For reasons of supply, tap water was used. It was assumed that because of the coarse nature of the soil materials water quality would have (within limits) an insignificant effect on infiltration. The volume of water infiltrating was measured as the amount emptied from a buret to maintain a constant head at 1, 6, 11, 21, 31, 41, 51 and 61 min after the constant head was first established. Several initial readings were taken for periods up to 3 h;however, it was found that rates became fairly constant within 1 h. The high infiltration rates and low availability of water further restricted the measurement period to 1 h. Soil samples were taken to establish moisture content prior to measurements. Infiltration rates (cm/h) were calculated for each time interval and plotted against time to produce an infiltration curve for each soil.

4.2.9 Wettability

A measure of the wettability of several materials was made by placing a standard size water drop (0.3 ml) on the surface of the material and measuring the time, in seconds, for drop infiltration (Scholl, 1975). Savage et al. (1972) called this the water drop penetration time (WDPT). Soil is considered water repellent when

drops remain on the surface for 5 s or longer (Debano; in Scholl, 1975).

4.2.10 Saturated Hydraulic Conductivity

The saturated hydraulic conductivities of various materials were investigated using the laboratory procedures of Klute (1965). Disturbed samples were packed moist into columns 5 cm in diameter and 40 cm long, filling in 5 cm intervals to a depth of 20 to 25 cm. Samples were packed at each interval using a jig designed to drop the columns 1 cm. Packing continued until no further settling occurred. Peats required application of a light hand pressure to each layer. The samples were then saturated from the bottom for 16 h or more after which a constant head was established and 15 min later readings began on the volume of percolate per unit time. Readings were taken until the rate leveled off, usually within 1 h. The hydraulic gradient was kept below 1 due to the coarse nature of the materials. Tap water was used because the rapid percolation necessitated large volumes of water. Water temperatures were recorded and were found to vary between 21 and 25 C. Measurements were replicated four times.

4.3.0 Chemical Determinations

4.3.1 pH and Electrical Conductivity

The pH was determined potentiometrically using a mixture

of 20 g soil (2 g peat) to 50 ml of distilled water. Electrical conductivity was measured using a conductivity bridge on a saturated paste extract (Ballantyne, 1976).

4.3.2 Total Carbon and Total Nitrogen

Total carbon content of peat materials was determined on ovendry samples with a Leco induction furnace (McGill, 1976). Duplicate samples were used.

Total nitrogen content of mineral samples was determined by the semi-micro Kjeldahl procedure, without pre-treatment to include nitrate and nitrite (McGill, 1976). Ovendry (70 C) plant and peat samples were passed through a 1 mm (20 mesh) sieve prior to use. Plant materials were pre-treated to include nitrate and nitrite, however peat was treated similarly to mineral soils. Again, duplicate samples were used. The C:N ratio of the peat materials was derived from these total carbon and nitrogen determinations.

4.3.3 Exchangeable Cations and Cation-Exchange Capacity

The exchangeable cations and CEC were determined using two methods of extraction. In both cases moist peat samples were used, although results are expressed using the ovendried weight. The first method was a neutral salt extraction (Osborne, 1976) and the second a buffered (pH 7.0) extract solution (Chapman, 1965). The exchangeable cations were determined by atomic adsorption

(Perkin-Elmer, 1973).

The neutral salt solutions used for extraction of cations included 2N sodium chloride for calcium, magnesium and potassium and 2N potassium chloride for sodium. Separate standards were prepared using both extracting solutions. The neutral salt CEC was calculated as the sum of exchangeable Ca + Mg + Na in me/100 g ovendry weight.

Exchangeable cations were also determined using buffered ammonium acetate at pH 7.0. The buffered CEC was determined by ammonium replacement and steam distillation (Bremner, 1965).

The CEC values were converted from a weight to volumetric expression by multiplying by the bulk density of the material. Exchangeable aluminum and hydrogen were not determined.

4.3.4 Extractable Phosphorus

Extractable phosphorus was determined on samples of moist peat and air-dried sand using the dilute acid (0.002N sulfuric acid) soluble extraction and Molydate blue colorimetric determination of orthophosphate (Jackson, 1958).

4.3.5 Mineral Nitrogen

Ammonium-and nitrate-nitrogen were determined by steam distillation using air-dried materials and results are expressed on this basis (Bremner, 1965).

4.3.6 Lime Requirement

The lime requirement of materials was determined by the addition of increments of calcium hydroxide, $Ca(OH)_2$, to 20 g of mineral soil or 2 g of moist peat in 100 ml of distilled water. The mixture was stirred intermittently for three days after which time the pH was determined. To convert from $Ca(OH)_2$ to $CaCO_3$ requirement, the former rate was multiplied by a factor of 1.35 (equal to the molecular weight of $CaCO_3$ divided by the molecular weight of $Ca(OH)_2$).

5.0 EXPERIMENTAL DESIGN

5.1.0 Laboratory Studies

5.1.1 Hydraulic Conductivity Experiment

The saturated hydraulic conductivity of a soil is a measure of its ability to transmit water. Infiltration of water into soil depends, in part, on the permeability of the soil (Baver et al., 1972) therefore measurement of hydraulic conductivity provides information on a soil's ability to accept water. Soil drainage, an important part of the field moisture regime, is also related to the hydraulic conductivity. Sand-textured soils tend to be rapidly drained, influencing amount of plant available water and leaching losses of plant nutrients.

The influence of peat amendments on the hydraulic conductivity of tailing sand was examined in the laboratory. Fluvial sand was also compared to the tailing sand. The saturated hydraulic conductivity experiment consisted of measuring the rate of flow of water through: tailing sand; fluvial sand; fibric (acid) peat (both air-dried and moist samples); mesic (Om layer) peat (again, both air-dried and moist samples) and mixtures of tailing sand with the four peats. Important properties of these materials are given in Tables 10, 11 and 13. Peat was added to tailing sand in three rates: 25, 50 and 75 percent by volume. The materials were prepared as discussed in section 4.1.0 and the hydraulic conductivity of the eighteen materials was measured as described in section 4.2.10. Table 15 lists the bulk densities of the materials in the columns.

Table 15. Bulk densities of materials used in the saturated hydraulic conductivity determinations and in the soil cores for 0, 0.1 and 0.06 bar moisture tension determinations.

Materials	Bulk density (g/cc)**	
	Moist sample*	Dried sample*
Tailing sand	- (-)	1.37 (1.35)
Fluvial sand	- (-)	1.42 (1.34)
Fibric (acid) peat	0.07 (0.07)	0.09 (0.06)
Mesic (Om) peat	0.14 (0.11)	0.12 (0.12)
Tailing sand + 25 % fibric peat	1.27 (1.26)	1.18 (1.16)
" " + 50 % " "	1.01 (1.01)	0.94 (0.94)
" " + 75 % " "	0.57 (0.57)	0.50 (0.45)
Tailing sand + 25 % mesic peat	1.15 (1.10)	1.13 (1.12)
" " + 50 % " "	0.88 (0.79)	0.89 (0.80)
" " + 75 % " "	0.57 (0.52)	0.54 (0.44)

- not determined.

* in each case the first number is the mean bulk density (based on two replications) of the hydraulic conductivity columns while the second number (in parenthesis) is the mean bulk density (based on three replications) of the soil cores from the moisture tension determinations.

** bulk densities based on saturated soil volume and ovendry (105 C) weight.

Results were compared by analysis of variance and Duncan's multiple range test (Steele and Torrie, 1960).

5.1.2 Soil Moisture Retention and Porosity Measurements

Moisture retention curves reveal information on three soil properties which are important factors in moisture conservation, infiltration rates and plant growth: (1) total soil porosity, (2) pore-size distribution and (3) plant available water. Total soil porosity is a measure of the maximum water holding capacity of a material. The distribution of the total porosity between macro-and micro-pores (Buckman and Brady, 1971; Farmer and Richardson, 1976) has important influences on infiltration rates, moisture retention and soil aeration. The macro-pores or air porosity are the soil voids which are drained under low moisture tensions (0.06 bar). Only the portion of soil water held between 0.33 and 15 bar moisture tension is available to plants (Buckman and Brady, 1971) and the greater this amount the lower is the possibility of growth limitations due to moisture deficiencies. Sand-textured soils generally have a low total porosity with a moderate to low air porosity and generally a very low available water storage capacity.

Peat additions to tailing sand were examined in laboratory studies as a means of improving soil moisture and porosity characteristics. The two sands were also compared.

Moisture retention characteristics were determined for eighteen materials including tailing sand, fluvial sand, fibric (acid)

peat (both air-dried and moist samples), mesic (Om layer) peat (again, both air-dried and moist samples) and mixtures of tailing sand and the four peats. Properties of the individual materials were given in Tables 10, 11 and 13. Peat was added to the tailing sand in rates of 25, 50 and 75 percent by volume. The preparation of the samples and measurement of moisture content at 0, 0.1, 0.06, 0.3 and 15 bar moisture tension was described in section 4.1.0 and 4.2.7, respectively. Moisture contents of the sand-peat mixtures were not measured at 0.01 bar tension although all other samples were. The moisture contents are expressed volumetrically, using the bulk densities of the materials at saturation (Table 15) to convert from a weight basis, allowing a better comparison of materials which vary greatly in bulk density. From these values, porosity and pore-size distribution properties and available water levels were obtained.

5.1.3 Buffering Capacity Measurements

The ability of a soil to resist large changes in pH is an important long-term consideration in reclamation. A soil which becomes excessively acid or basic may limit plant growth. Sand-textured soils, because of low clay and organic matter content, generally have a poor buffering capacity. Therefore, the buffering capacities of the various individual materials were determined. Increments of base (calcium hydroxide) or acid (sulfuric acid) were added to soil-water mixtures. The materials used included the

tailing sand, fluvial sand, fibric (acid) peat, mesic (Om) peat and the fibric (Of) peat described in Tables 10, 11 and 13.

The soil material was weighed out (20 g of air-dried sand or 10 g of moist peat), increments of base or acid added, and deionized, distilled water used to make the mixture up to 50 ml. Acid and base were added to the sands in increments of 4, 8, 12 and 16 me H^+ (or OH^-) /100 g of air-dry soil and to moist peat at rates of 20 and 24 me H^+ (or OH^-) /100 g as well as the former rates. After three days, with stirring at regular intervals, the pH of each treatment was measured. Buffering curves were made by plotting the amount of base or acid added against pH for each increment. The amount of soil materials was converted to a volumetric expression by determining the ovendry (105 C) weight of the peat and using the bulk densities of the soil materials (Table 13 for peats and 1.4 g/cc for sands).

5.2.0 Greenhouse Studies

The ability of tailing sand to support growth of a vegetative cover is an important step towards reclamation objectives. However, initial indications have been that the tailing sand is a poor growth medium.

The influence of peat additions on the fertility of tailing sand and the resulting yields of a grass-legume crop were the subject of an experiment carried out in a greenhouse. Treatments were also included to measure the response of the crop to applications of

fertilizer and lime.

Three peats, tailing sand and 1:1 volumetric tailing sand-peat mixtures (using each of the three peats) made up the seven soil materials used in the experiment. Properties of the tailing sand were given in Tables 10 and 11. The peats consisted of the fibric (acid) peat, the fibric (Of) peat and the mesic (Om) peat each of which is described in Tables 11 and 13.

The materials and mixtures were initially prepared as outlined in section 4.1.0 and all had been air-dried. The materials were then weighed-out, wetted to an approximate field capacity moisture content (Table 16) with distilled water and placed in sealed-bottom plastic pots. The pots were 12.7 cm in diameter and held between 1 and 1.3 liters. The soils were kept near field capacity moisture content throughout the experiment with every-other-day weighings and replacement of lost water.

Three treatments were applied to each of the seven soil materials: (1) nil or control treatment, (2) fertilized treatment and (3) fertilized plus limed treatment. All fertilized and fertilized plus limed pots received nitrogen at 168 kg N/ha, phosphorus at 56 kg P/ha, potassium at 128 kg K/ha and sulfur at 11 kg S/ha. The nitrogen application was split into an initial 112 kg N/ha and an additional 56 kg N/ha one month later. All fertilizer was applied on a weight per unit area basis. Reagent grade chemicals were the nutrient sources and included: NH_4NO_3, KH_2PO_4, KCl and $Na_2SO_4 \cdot 10H_2O$. The nutrients were applied in solution to the surface of the pots and leached downward with pot watering immediately

after application.

Table 16. Bulk densities and field capacity moisture content of the soil materials used in the greenhouse studies.

Soil material	Bulk density (g/cc)*	Field capacity (% by volume)
Tailing sand	1.15	12
Fibric (acid) peat	0.05	33
Fibric (Of) peat	0.07	25
Mesic (Om) peat	0.10	32
Tailing sand + fibric (acid) peat	0.83	32
Tailing sand + fibric (Of) peat	0.88	23
Tailing sand + mesic (Om) peat	0.85	30

* bulk density at field capacity moisture content as determined from greenhouse pots.

Lime ($CaCO_3$) was applied to the peats at predetermined rates (see section 4.3.6) to raise the soil pH to near neutral levels. The fibric (acid) peat received 17.9 tonnes/ha of $CaCO_3$; the fibric (Of) peat, 11.2 tonnes/ha of $CaCO_3$; and the mesic (Om) peat received 4.5 tonnes/ha of $CaCO_3$. These same rates were applied to the respective tailing sand-peat mixes. Although not warranted by its pH, lime was also applied to tailing sand at a rate of 4.5 tonnes/ha of $CaCO_3$. Sodium dominates the exchange complex of tailing sand and liming was attempted to determine the effect of added calcium.

All pots were sown to a mixture of Carleton bromegrass (Bromus inermis) and inoculated Rambler alfalfa (Medicago sativa). The pots were thinned out to 5 plants per species per pot in two stages at two and three weeks after seeding.

Germination counts were made twelve days after seeding. Dry weight (70 C) plant top yields were obtained at harvest two months after seeding. Observations were made at harvest on the occurrence of nodulation on alfalfa roots. The pH and NH_4-N and NO_3-N levels of the soil materials were also determined at this time.

The experiment was carried out under 16 h/d of lighting and although not fully controlled, temperatures were usually between 19 and 22 C. A randomized complete block design was used, with three replications. Analysis of variance and Duncan's multiple range test were used to aid in interpretation of results.

5.3.0 Field Studies

5.3.1 Soil Erosion Studies

The effects applications of peat to tailing sand have on soil erosion and water runoff were the subject of a field study. In particular, effects of different types of peats, different methods of application and various rainfall characteristics were investigated.

Runoff plots were established on the GCOS, Ltd. tailing sand dyke north of Fort McMurray in July 1975 and monitored until October 1975 and again from May to September in 1976 (see Plate 1). The plots were located on the southeast facing slope of the dyke

Plate 1.

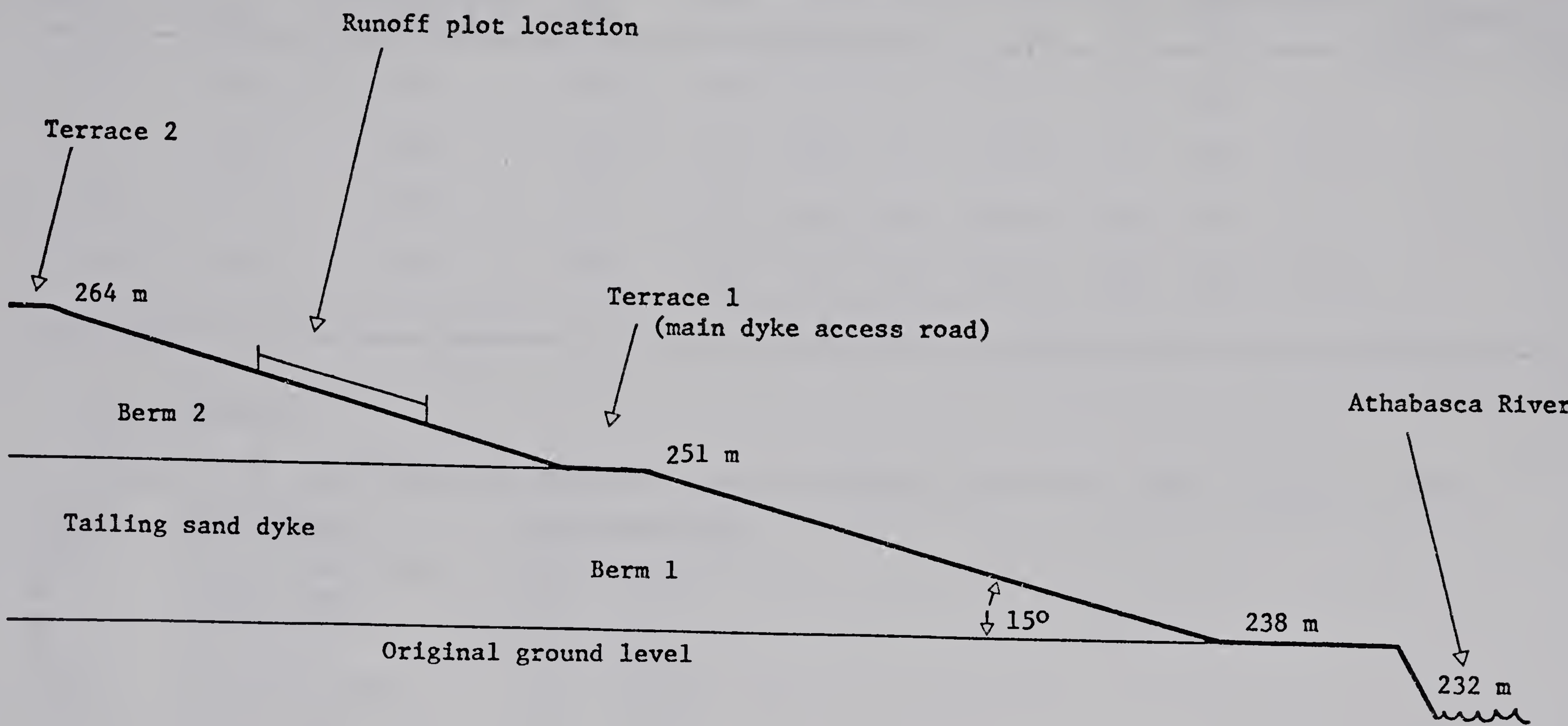
View of the runoff plot on the GCOS, Ltd. tailing sand dyke on August 17, 1975. The treatments are from the right, mesic peat mulch, fibric peat mulch plus lime, tailing sand, and mesic peat mixed-in followed by a second replication of these treatments (see Figure 2). Note also the runoff collection drums.

which had a slope of approximately 15° (Figure 1). Revegetation had been attempted previously in this area. However, gully erosion necessitated recontouring the site to a bare sand surface. Some of the properties of the tailing sand at the plot site are given in Table 17.

Eight plots were set out, each 2.4 m by 15.2 m and 0.0037 ha in area. Wood planks 1 cm by 30 cm were sunk 10 cm into the sand across the upper end of the plots to prevent runoff from the slope above the plots from entering the plots. Adjacent plots were separated by 15 cm high plastic edging sunk approximately 6 cm into the sand. At the lower end of the plots, runoff was directed by pieces of edging towards a central V-shaped notch in a second 1 cm by 30 cm plank and thereafter along a flume leading to a collection drum. A control drum and flume were also set up because the collectors were exposed to rainfall. Volumes of runoff water in the treatment barrels were corrected by an amount equal to that in the control collector. The drums held approximately 214 liters.

Four treatments were applied in duplicate to the plots (Figure 2). The first treatment was the existing tailing sand. The second treatment had approximately 12 cm of fibric (acid) peat applied as a mulch to the surface of the tailing sand. The initial properties of this peat are given in Tables 11 and 13. The third treatment was an application of a similar amount, but different type of peat, approximately 12 cm of mesic "stockpiled" peat as a mulch to the surface of the sand. Initial properties of this peat are also given in Tables 11 and 13. The fourth treatment received the same amount

Figure 1. Cross-section of runoff plot location on the GCOS, Ltd. tailing sand dyke. Elevations are above mean sea level from Lesko, 1974 and Klym and Berry, 1976.



Scale: 1 cm = 6 m

Table 17. Some properties of the tailing sand at the runoff plot site on August 14, 1975 prior to application of treatments.

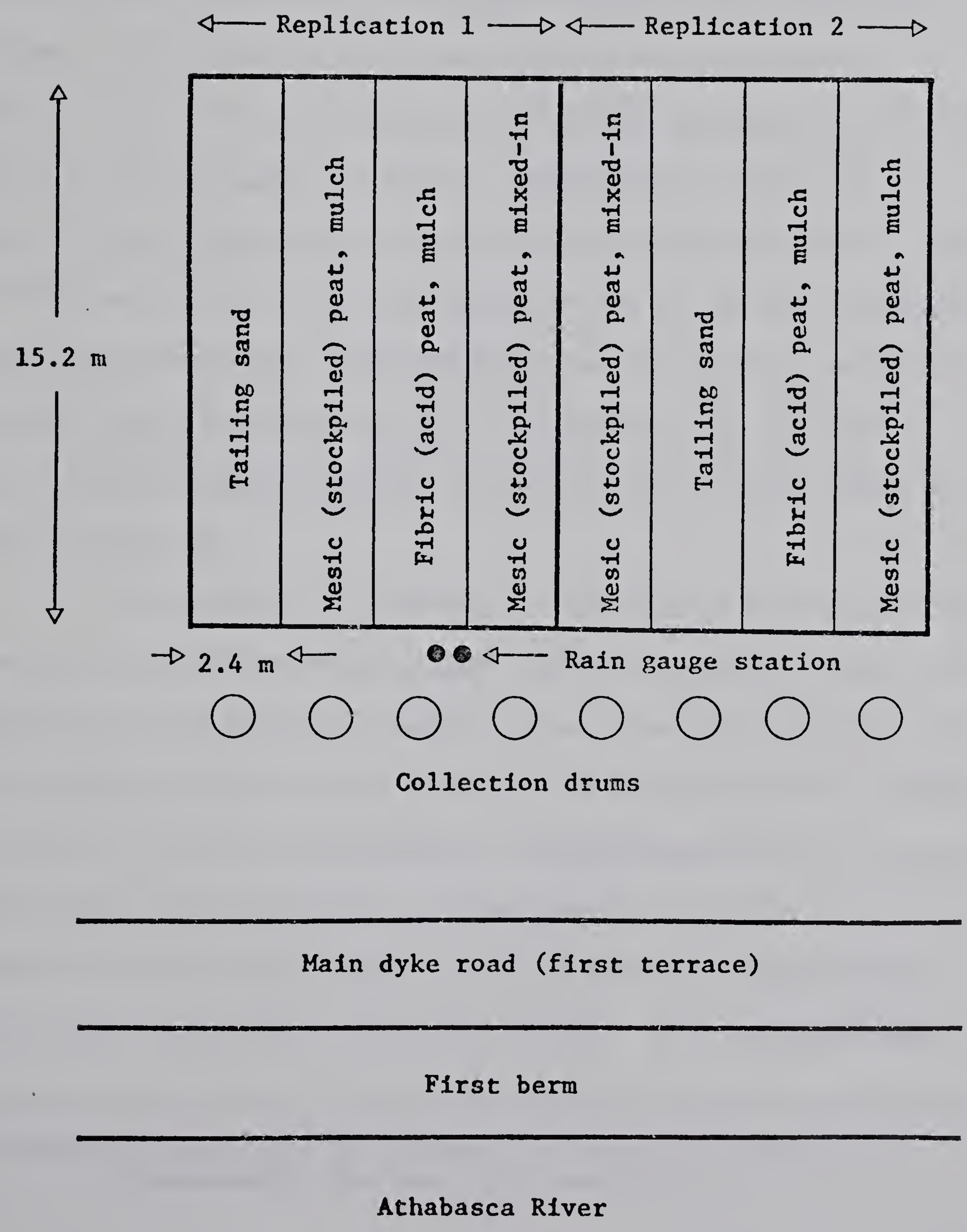
Depth (cm)	pH	Electrical conductivity (mmho/cm)	Total N (%)	Particle-size analysis*								Mineral nitrogen (kg/ha)	
				VCS	CS	MS	FS	VFS	Total S	Si	C	NH_4-N	NO_3-N
0 - 15	8.0	0.32	0.03	0.03	1.6	6.5	74.1	11.5	94	5	1	3	0
15 - 30	7.8	0.33	0.01	0.1	0.8	5.8	77.2	11.1	95	4	1	0	0
30 - 60	7.7	0.32	0.01	0.2	0.6	5.6	77.3	11.3	95	4	1	0	0
60 - 90	7.6	0.33	0.01	0.2	0.7	4.9	79.4	9.8	95	4	1	-	-

\- not determined.

* percent of the total sample in each size class as indicated below (Can. Dept. of Agric., 1974):

Symbol	Description	Size range (mm)
VCS	very coarse sand	1.0 - 2.0
CS	coarse sand	0.5 - 1.0
MS	medium sand	0.25 - 0.5
FS	fine sand	0.10 - 0.25
VFS	very fine sand	0.05 - 0.10
Total S	total sand	0.05 - 2.0
Si	total silt	0.002 - 0.05
C	total clay	less than 0.002

Figure 2. General layout of the runoff plot on the GCOS, Ltd. tailing sand dyke (Not to scale).



of mesic "stockpiled" peat as the third, however after application as a mulch it was subsequently worked into the tailing sand so that the top 20 cm became a mixture of tailing sand and peat at approximately a 1:1 volumetric ratio. Tables 18 and 19 show the effect these additions had on soil properties.

All treatments received similar management practices with one exception, lime ($CaCO_3$) was applied to the fibric (acid) peat treatment at a rate of 12.2 tonnes ($CaCO_3$)/ha one day prior to seeding. All plots were fertilized and seeded on August 17, 1975 at the rates shown in Table 20 and 21, respectively. Both seed and fertilizer were broadcast and worked lightly into the surface. Oats were sown as a cover crop, with the objective of rapidly establishing a protective vegetative layer and providing some organic matter to the soil in the following year. The treatments also received a second and third application of fertilizer the following summer as shown in Table 20.

A rain gauge was installed at the site in 1975 and in 1976 a rainfall intensity-duration gauge[1] was also installed. This latter gauge had a 15 cm rainfall capacity and an 8 day spring driven clock. Data on daily rainfall in the area for the study period was obtained courtesy of GCOS, Ltd. who maintain a meteorological station approximately 3 km from the plot site. Measurements of rainfall and the amount of soil and water runoff collected were made approximately every third week in 1975 and weekly in 1976. From this data the

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[1]Footnote:a Stevens Type Q6 recorder from Leupold and Stevens Instruments, Portland, Ore. was used.

Table 18. Bulk densities of tailing sand and peat additions to tailing sand as measured on the runoff plot treatments.

Soil material	Depth (cm)	Bulk density (g/cc)*
Tailing sand	0 - 7.5	1.40 ± 0.01
	7.5 - 15	1.42 ± 0.01
	15 - 22.5	1.44 ± 0.01
	22.5 - 30	1.43 ± 0.05
	38 - 45.5	1.49 ± 0.05
	53 - 60.5	1.40 ± 0.05
Fibric (acid) peat, mulch	0 - 6.1	0.18 ± 0.03
Mesic (stockpiled) peat, mulch	0 - 6.4	0.21 ± 0.03
Mesic (stockpiled) peat, mixed-in	0 - 7.5	1.33 ± 0.03
	7.5 - 15	1.34 ± 0.17

* mean bulk density and standard deviations based on three replications of the tailing sand samples and four replications of the peat samples.

Table 19. Influences of the equal volumes (12 cm layer) of fibric (acid) peat and mesic (stockpiled) peat added to the run-off plot treatments.*

Parameter influenced	Type of peat added to tailing sand: Fibric (acid) peat	Mesic (stock-piled) peat
Dry weight of material added (tonnes/ha)	60	252
Organic matter added (tonnes/ha)**	58	186
Total nitrogen added in peat (kg/ha)	530	4210
Increase in total nitrogen content of top 30 cm (%)***	0.014	0.108

* figures based on properties of the peats listed in Tables 11 and 13.

** organic matter equals dry weight of material added minus the ash content.

*** based on 3.9×10^6 kg/ha of peat and tailing sand in the top 30 cm, that is, a bulk density of 1.30 g/cc.

Table 20. Fertilization record of the runoff plot on the GCOS, Ltd. dyke. All treatments received the same rates and types of fertilizer which was broadcast-applied.

Date of application	Nutrient	Rate* (kg/ha)	Commercial fertilizer source
1975			
August 17	N	128	34- 0- 0 (ammonium nitrate)
		+ 14.5	11-55- 0 (ammonium phosphate)
	total:	142.5	
	P_2O_5	72.5	11-55- 0
	K_2O	89.5	0- 0-60 (potassium chloride)
1976			
June 9	N	78.5	34- 0- 0
		+ 9	11-55- 0
	total:	87.5	
	P_2O_5	45	11-55- 0
	K_2O	68.9	0- 0-60
1976			
July 15	N	64.3	34- 0- 0
		+ 25.5	11-55- 0
	total:	89.8	
	P_2O_5	127.5	11-55- 0
	K_2O	nil	

* rates given as: -total nitrogen
-water soluble phosporus (P_2O_5)
-water soluble potassium (K_2O)

percent of rainfall lost as runoff was calculated and the amount of soil eroded was tabulated.

Table 21. Seeding rates used on the runoff plot on the GCOS, Ltd. dyke. The seed was broadcast on August 17, 1975 with all treatments receiving the same rates and mix.

Plant (cultivar)	Seeding rate (kg/ha)
Cover crop:	
Oats (Pendek)	59
Permanent species:	
Alfalfa (Rambler)*	9
Bromegrass (Carleton)	9
Creeping red fescue (Boreal)	9
Crested wheatgrass (Nordan)	9

* the alfalfa was inoculated.

In September 1975, severe damage was caused to the first three treatments on the left-hand side (Replication 1) of the plot by runoff from areas above and outside of the plot. Although some data was salvaged from these plots, runoff could no longer be collected. In 1976 only the five plots on the right side of the site (Replication 2) were functioning (Figure 2).

Along with the runoff studies, a number of other investigations were also made using these plots. These studies are discussed in the remainder of this chapter.

5.3.2 Infiltration Experiment

The rate of water intake in tailing sand and the influence of peat amendments on infiltration was studied in the field using the four treatments on the runoff plot (see section 5.3.1) as well as the fluvial sand site near the Mildred Lake AOSERP camp (see Table 12). Infiltration rates were determined by the method described in section 4.2.8 using four replications. The Student's "t" test was used to test the significance of differences between the constant rate portions (11 to 61 min after constant head established) of the treatments. The soil moisture content of each treatment was determined from samples taken prior to infiltration determinations.

5.3.3 Wettability Experiment

Field observations indicated that wettability of the tailing sand surface might be a factor controlling infiltration and influencing soil erosion. The wettability of the tailing sand and the peat treatments of the runoff plot (see section 5.3.1) were measured using the method described in section 4.2.9.

While these measurements were underway it was observed that the wettability of tailing sand varied with depth. Samples of tailing sand from the undisturbed surface of the plot, from 2 to 5 cm below the surface and from 100 to 130 cm below the surface were subjected to wettability measurements. (Samples from areas adjacent to the plot were found to exhibit the same properties.) The wettability of

a sample of fluvial sand (0 to 15 cm layer, air-dried) was also measured for comparison to the tailing sand.

Measurements on each treatment were replicated 12 times and an analysis of variance and Duncan's multiple range test were used to determine the significance of differences amoung treatments.

5.3.4 Productivity Measurements

Yields of above ground plant growth were taken as a measure of productivity of the various treatments on the runoff plot (see section 5.3.1). Because the prime objective of the plots was to study erosion caution was necessary in measuring productivity to avoid practices which could influence runoff. For this reason small (50 cm by 50 cm) quadrat sampling was used.

Three harvests were made on the plots. In October 1975, two months after seeding, the cover crop of oats was harvested. Three quadrats were taken per treatment from the four treatments of both replications. In 1976, the grass-alfalfa crop was harvested on July 15 and again on September 8. In July, the one remaining replication was harvested using four quadrats per treatment. The harvested areas were marked and the second growth was harvested in September. Forage crop yields were separated into grass and alfalfa. All plant yields are expressed on an ovendried (70 C) weight basis.

Observations of general plant conditions were noted.

5.3.5 Plot Monitoring Program

The runoff plot on the GCOS, Ltd. dyke was monitored for several factors important to the establishment of vegetation.

During 1975, the soil pH and mineral nitrogen content of the various treatments were determined on three dates, August 14 (prior to any treatment), August 26 (after all amendments had been applied) and October 9 (at harvest). The soil was sampled in intervals to depths up to 90 cm. Each sample consisted of soil from four cores per treatment.

Also in 1975, temperatures were taken of the soil at depths of 5, 20 and 30 cm under the four treatments. Thermister probes were installed at a station in each treatment. Air temperatures, 30 cm above the tailing sand surface were also recorded.

In 1976, the soil pH and mineral nitrogen content in the top 90 cm were again monitored through the growing season using the four treatments in replication 2 (Figure 2). The soil moisture content at various depths and for the total 90 cm under the four treatments was determined gravimetrically on bi-monthly samples.

6.0 RESULTS AND DISCUSSION

6.1.0 Laboratory Experiments

6.1.1 Hydraulic Conductivity

The soil materials exhibited a wide range in saturated hydraulic conductivities (Table 22) with values in the moderately rapid to very rapid permeability classes (Klute, 1965). This suggests wide differences in porosity and pore-size distribution.

Tailing sand drains very rapidly, however fluvial sand drains twice as fast again. McCoy et al. (1976) reported a similar relationship between the hydraulic conductivities of tailing sand and aeolian sand from the Oil Sand region. The higher portion of medium and coarse sand particles in the fluvial sand (Table 10) contributes to a larger average pore-size. Because of the lack of aggregation in a soil with a large percentage of sand-size particles, pore-size distribution is perhaps the most important factor influencing hydraulic conductivity.

The peats exhibited a wide range in hydraulic conductivities. The fibric (acid) peat had an extremely rapid rate of over 200 cm/h, while the mesic (Om) peat had the slowest rate (although still moderately rapid) at 10 cm/h. A decrease in hydraulic conductivity with increasing degree of decomposition is consistent with results presented by Boelter (1965; 1968) and Lindsay et al. (1976). Irwin (1968) suggested that the range in hydraulic conductivities in peat is related to the volume, size and distribution of pores. The rate of water movement through peat varies from significantly slower to

Table 22. The saturated hydraulic conductivities of sands, peats and tailing sand-peat mixtures as determined in the laboratory experiment.

Soil material	Hydraulic conductivity (cm/h)*	
	moist samples	air-dried samples
Tailing sand	-	46 ghi
Fluvial sand	-	91 d
Fibric (acid) peat	203 b	283 a
Mesic (Om) peat	10 j	200 b
Tailing sand + 25 % fibric (acid) peat	50 fgh	59 ef
" " + 50 % " " "	45 ghi	49 fgh
" " + 75 % " " "	54 efg	105 c
Tailing sand + 25 % mesic (Om) peat	40 hi	50 fgh
" " + 50 % " " "	36 i	42 ghi
" " + 75 % " " "	13 j	65 e
	$S\bar{x}$ = 3.9**	

\- indicates measurements not made.

* treatments not followed by the same letter are significant from each other at the 5 % level of significance as judged by Duncan's Multiple Range Test.

** standard error of the mean.

significantly faster than its rate through tailing sand (Table 22).

Additions of fibric (acid) peat to tailing sand in 25, 50 and 75 percent proportions did not significantly affect the hydraulic conductivity of the sand and only the largest (75 percent) addition of mesic (Om) peat significantly affected the rate, causing a large decrease.

Air-drying caused significant increases in the hydraulic conductivities of both the fibric (acid) and mesic (Om) peat. In the latter case rates increased by a factor of 20, likely indicating a major alteration in the physical structure of the peat. Lindsay et al. (1976) reported that air-drying peat decreased the hydraulic conductivity. Variations in method of determination, particularly in sample preparation, may have been the cause for this difference. In the present study peat samples were air-dried and then passed through a 6 mm screen while Lindsay et al. (1976) used a finer (2 mm) mesh size. The coarser screening would be expected to produce a greater amount of macro-pores and hydraulic conductivity. The addition of air-dried peat to tailing sand increased the hydraulic conductivities relative to each respective moist peat increment (Table 22). However only the 75 percent air-dried additions produced significant increases in the permeability of the tailing sand.

Application of large portions of most peats to the surface of tailing sand will serve to quickly move water away from the surface, allowing a rapid infiltration rate to be maintained. This inturn conserves moisture and reduces soil erosion by reducing water runoff. The mesic (Om) peat appears to be less suitable than the fibric (acid)

peat except when the mesic peat is air-dried. Peat applied as a mulch tends to dry faster than mixed-in peat (Allison, 1973), therefore a mesic peat mulch may be as effective as a fibric peat in maintaining a high infiltration rate.

6.1.2 Moisture Retention and Porosity

The moisture retention curves of the two sands indicate low total porosity, rapid drainage of water as moisture tension increases towards 0.33 bar, and little plant available water (Figure 3). There is however, a major difference in the pore-size distribution of the two sands. As indicated in Table 23 only 6 percent of the porosity in tailing sand is air porosity, while the corresponding amount for the fluvial sand is 13 percent. The single-grain structure and lack of aggregation in the sands as well as the low silt, clay and organic matter content point to differences in the sand fraction as the factor influencing the air porosity. The fluvial sand contains larger amounts of coarse and medium-size sand particles (Table 10) and therefore has the greater air porosity. The large differences in hydraulic conductivity between the two sands (Table 22) is consistent with the pore-size distributions revealed through the retention curves. Pore-size distribution may also have an important influence on infiltration rate, with a large air porosity (or macro-pore percentage) promoting high infiltration rates (Farmer and Richardson, 1976).

The available water content of both sands is 2 percent (by volume) or 2 cm in a 100 cm root zone (Table 24). Takyi et al. (1977)

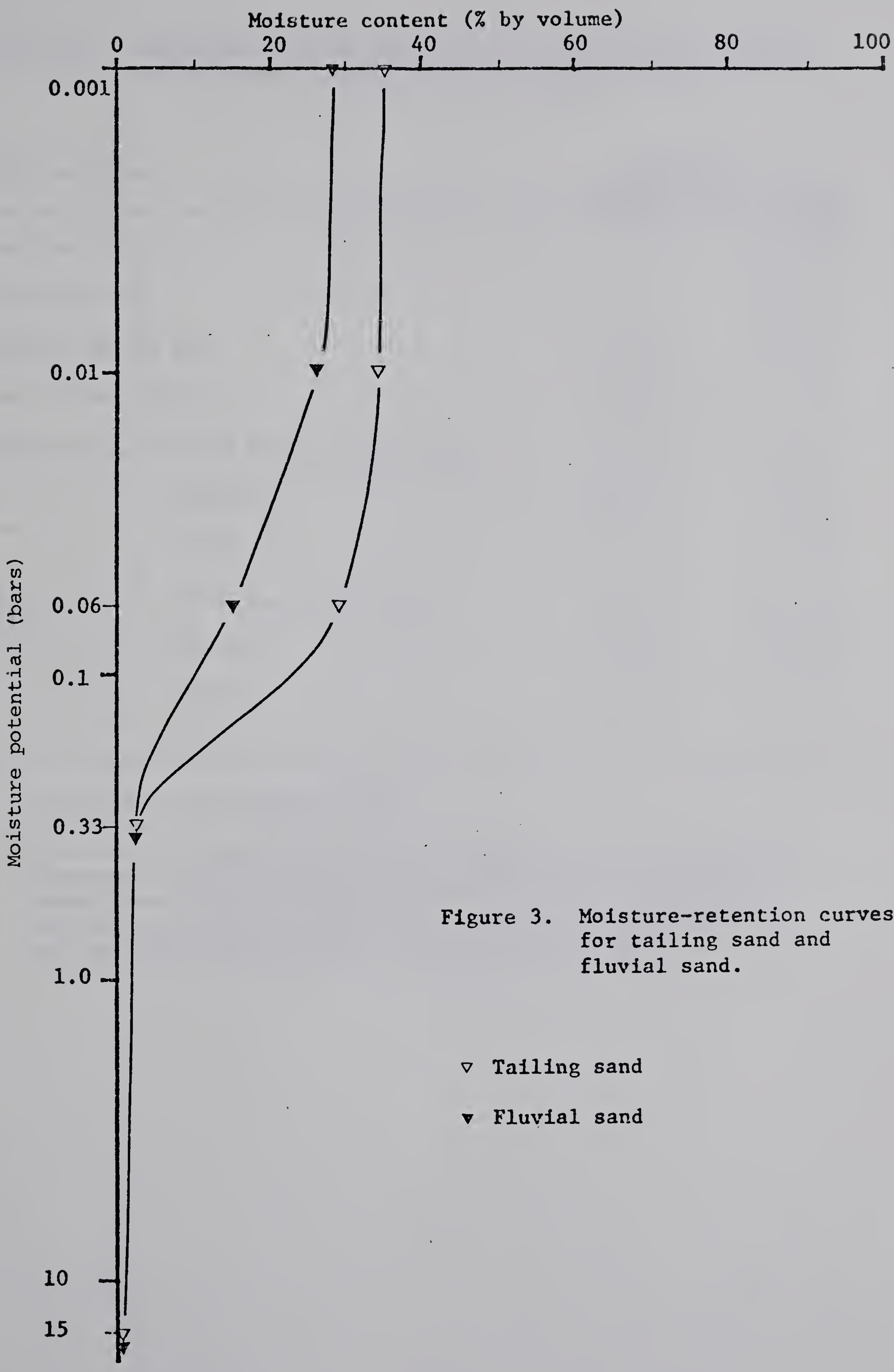


Figure 3. Moisture-retention curves for tailing sand and fluvial sand.

Table 23. Total porosity and air porosity of the soil materials as determined from moisture retention curves.

Soil material	Samples* moist	air-dried
Tailing sand	-	36 (6)
Fluvial sand	-	29 (13)
Fibric (acid) peat	91 (41)	73 (48)
Mesic (Om) peat	81 (22)	96 (45)
Tailing sand + 25 % fibric (acid) peat	51 (19)	58 (14)
" " + 50 % " " "	58 (21)	71 (27)
" " + 75 % " " "	72 (28)	77 (39)
Tailing sand + 25 % mesic (Om) peat	59 (14)	56 (15)
" " + 50 % " " "	70 (21)	68 (22)
" " + 75 % " " "	80 (18)	78 (31)

\- indicates measurement not made.

* for each soil material the first number is the total porosity (percent of total soil volume as pores) and the number in parentheses is the air porosity (percent of the total soil volume containing air when water is removed under 60 cm (0.06 bar) moisture tension from a saturated core sample).

Table 24. Available water content of the soil materials and the effect of air-drying on available water as derived from the moisture retention curves.

Soil material	Available water in samples (percent by volume)	
	moist	air-dried
Tailing sand	-	2
Fluvial sand	-	2
Fibric (acid) peat	10	4
Mesic (Om) peat	12	11
Tailing sand + 25 % fibric (acid) peat	3	3
" " + 50 % " " "	5	2
" " + 75 % " " "	7	0
Tailing sand + 25 % mesic (Om) peat	6	3
" " + 50 % " " "	13	5
" " + 75 % " " "	24	9

\- indicates measurement not made.

reported the 0.33 bar moisture percentage of tailing sand as 14 percent by weight (19 percent by volume) while Figure 3 shows a much lower value. The rapid change in water content between 0.06 and 0.33 bar moisture tensions may partially explain this difference. Moschopedis and Mitchell (1974) reported the field capacity moisture content of GCOS, Ltd. tailing sand as 3.5 percent by weight (5 percent by volume). Regier (1976) also found a similar, low (1.2 percent by weight) available water storage capacity for tailing sand.

The fibric (acid) peat (Figure 4) has a very high total porosity, characteristic of undecomposed peat (Table 5) and drains rapidly due to a very large air porosity (Table 23). The available water held by the fibric peat is considerably greater than that held by the sands (Table 24). However, as was found by Irwin (1968) the total volume of water held at tensions above 0.33 bar is small relative to the amounts held at lower moisture tensions.

The total porosity of mesic (Om) peat is somewhat less than the fibric peat although still high relative to most mineral soils. With a smaller air porosity (Table 23) the mesic peat exhibits lower drainage and larger amounts of available moisture (Table 24) than the fibric peat. These results are consistent with those obtained by Feustel and Byers (1936) and Boelter (1968).

Figure 4 also shows the effect of air-drying the peats. The total porosity of the fibric (acid) peat was decreased by drying whereas the total porosity of the mesic (Om) peat increased. Air-drying also increased the air porosity of both peats (Table 23), producing more rapid drainage as indicated by the shape of the

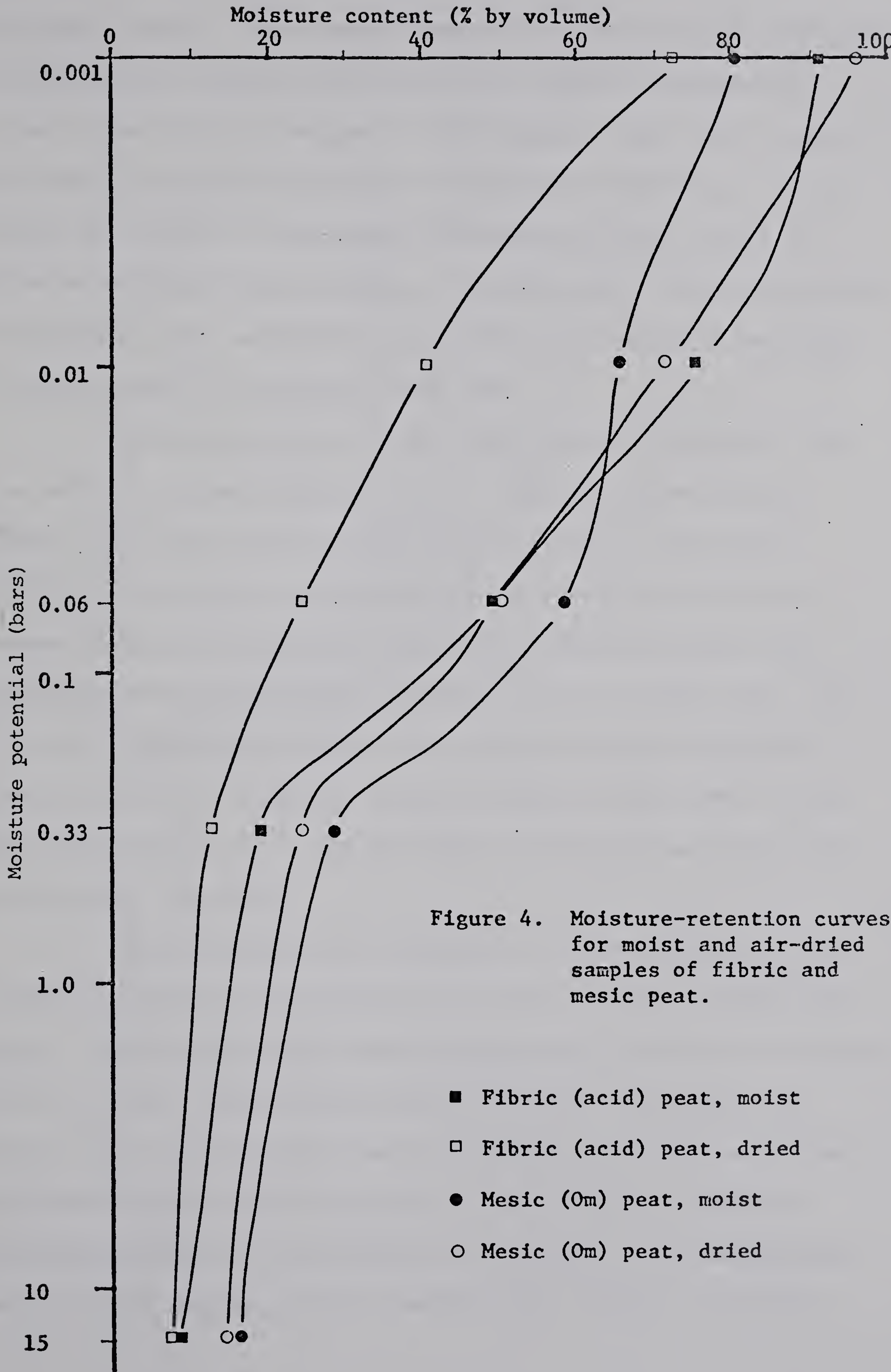


Figure 4. Moisture-retention curves for moist and air-dried samples of fibric and mesic peat.

■ Fibric (acid) peat, moist

□ Fibric (acid) peat, dried

● Mesic (Om) peat, moist

○ Mesic (Om) peat, dried

retention curves. These results compare with the increased hydraulic conductivities resulting from air-drying which were measured previously (Table 22). Puustjarvi (1968) suggests this effect is due to shrinkage of colloidal particles with only slow re-wetting. Observations at the time of measurement indicated that large pieces of fiber also shrunk upon air-drying. Air-drying also reduced the amount of available water held by both peats (Table 24) having a particularly great effect on the fibric (acid) peat.

The total porosity of the tailing sand was increased with the addition of peat (Figures 5 to 8). The differences between fibric (acid) peat and mesic (Om) peat were small. The initial addition of 25 percent peat resulted in an average 50 percent increase in the total porosity of the tailing sand and further peat additions continued to increase porosity, but at a slower rate. The 75 percent additions increased total porosity to approximately 80 percent by volume, a quantity similar to that of humic peats. Air-dry peat additions had a similar effect on the total porosity of the tailing sand (Table 23).

The air porosity of tailing sand increased with peat additions and the fibric peat produced the greater amount of these large pores. Table 23 shows that increasing the rate of moist peat addition above 25 percent caused little further increase in air porosity. However, the air-dried peats acted differently, with the larger peat additions causing further increases in air porosity. Therefore, heavy applications of either peat to the surface of the tailing sand will, upon air-drying, create a surface with a large air porosity

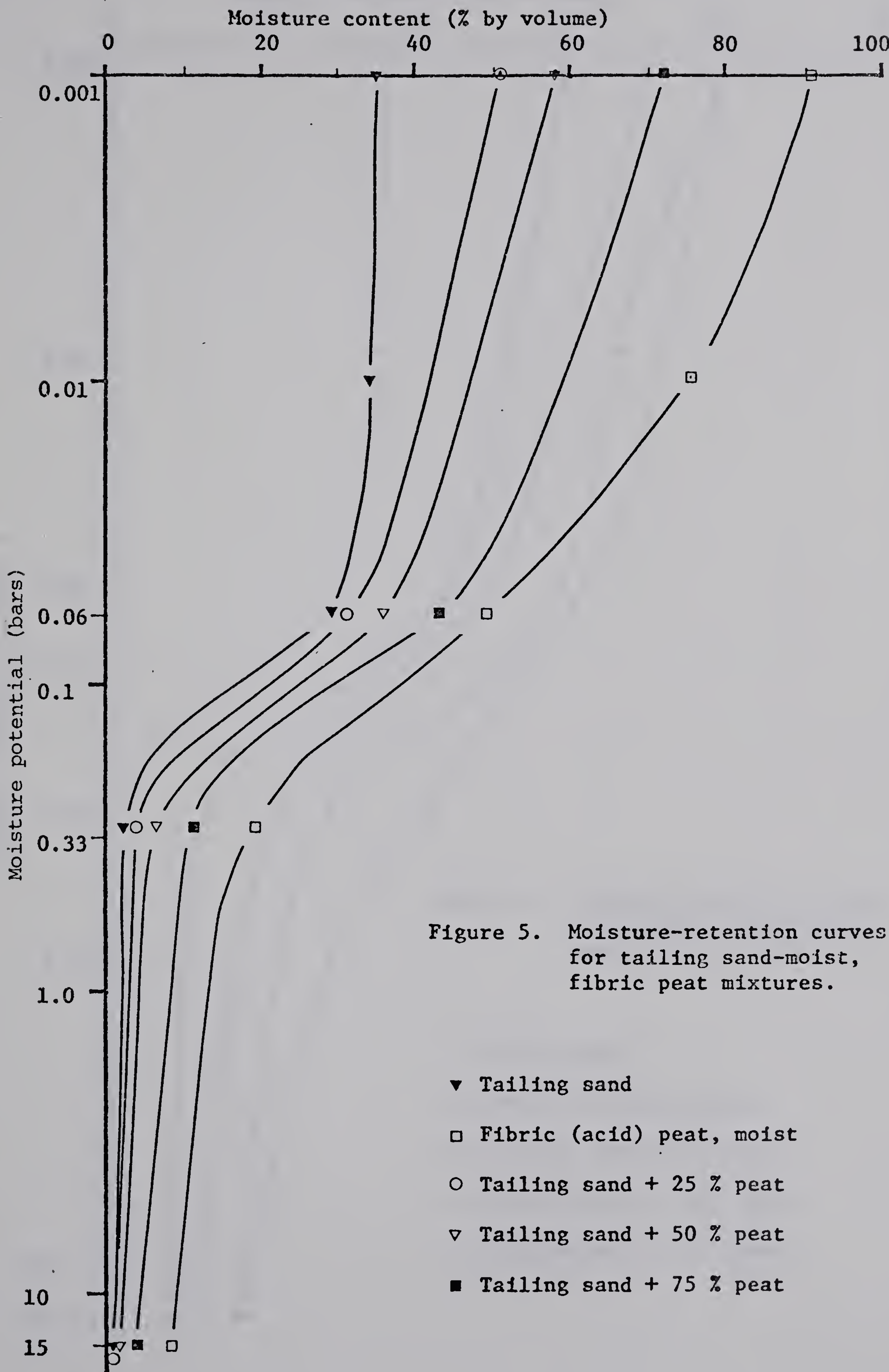


Figure 5. Moisture-retention curves for tailing sand-moist, fibric peat mixtures.

▼ Tailing sand

□ Fibric (acid) peat, moist

○ Tailing sand + 25 % peat

▽ Tailing sand + 50 % peat

■ Tailing sand + 75 % peat

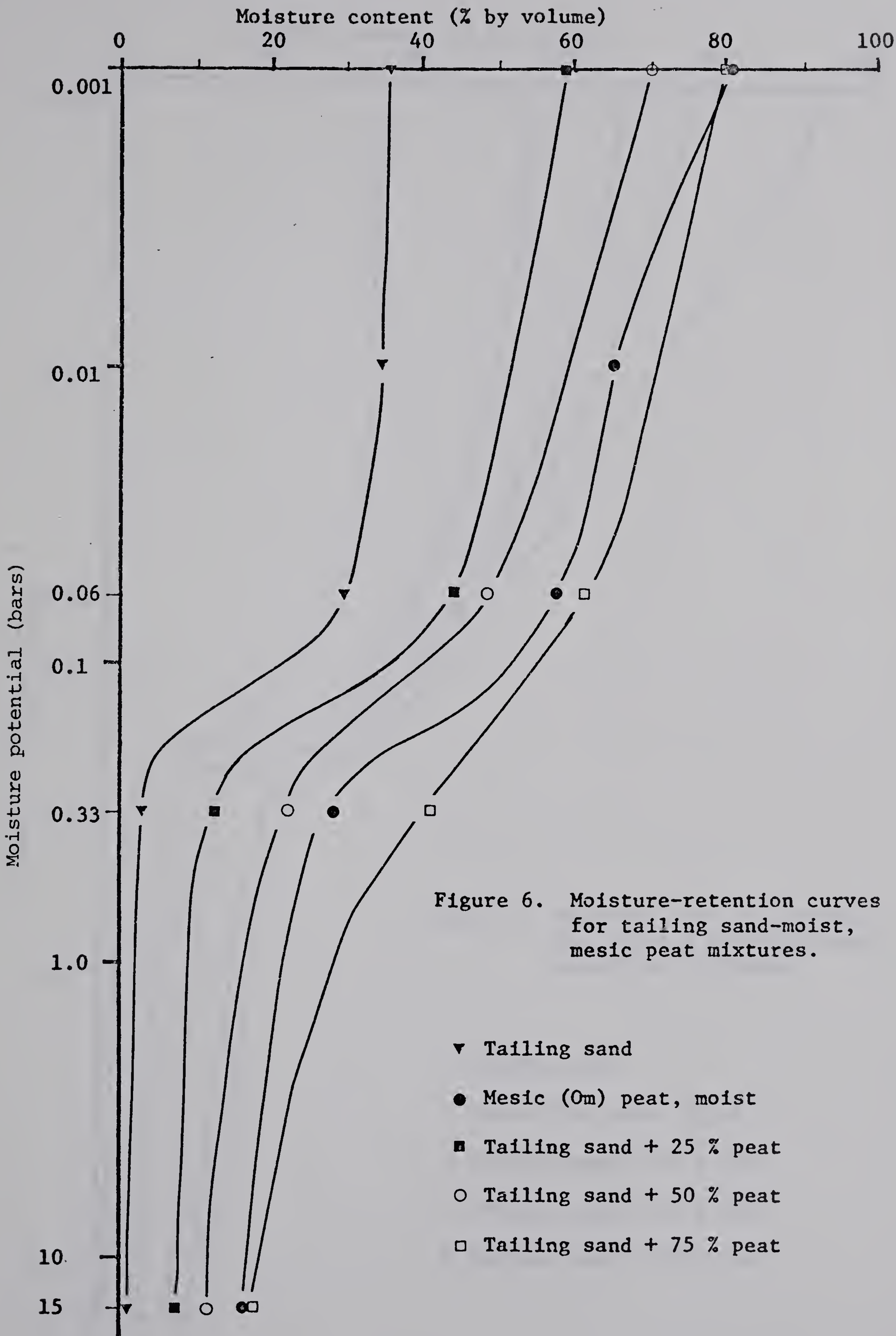


Figure 6. Moisture-retention curves for tailing sand-moist, mesic peat mixtures.

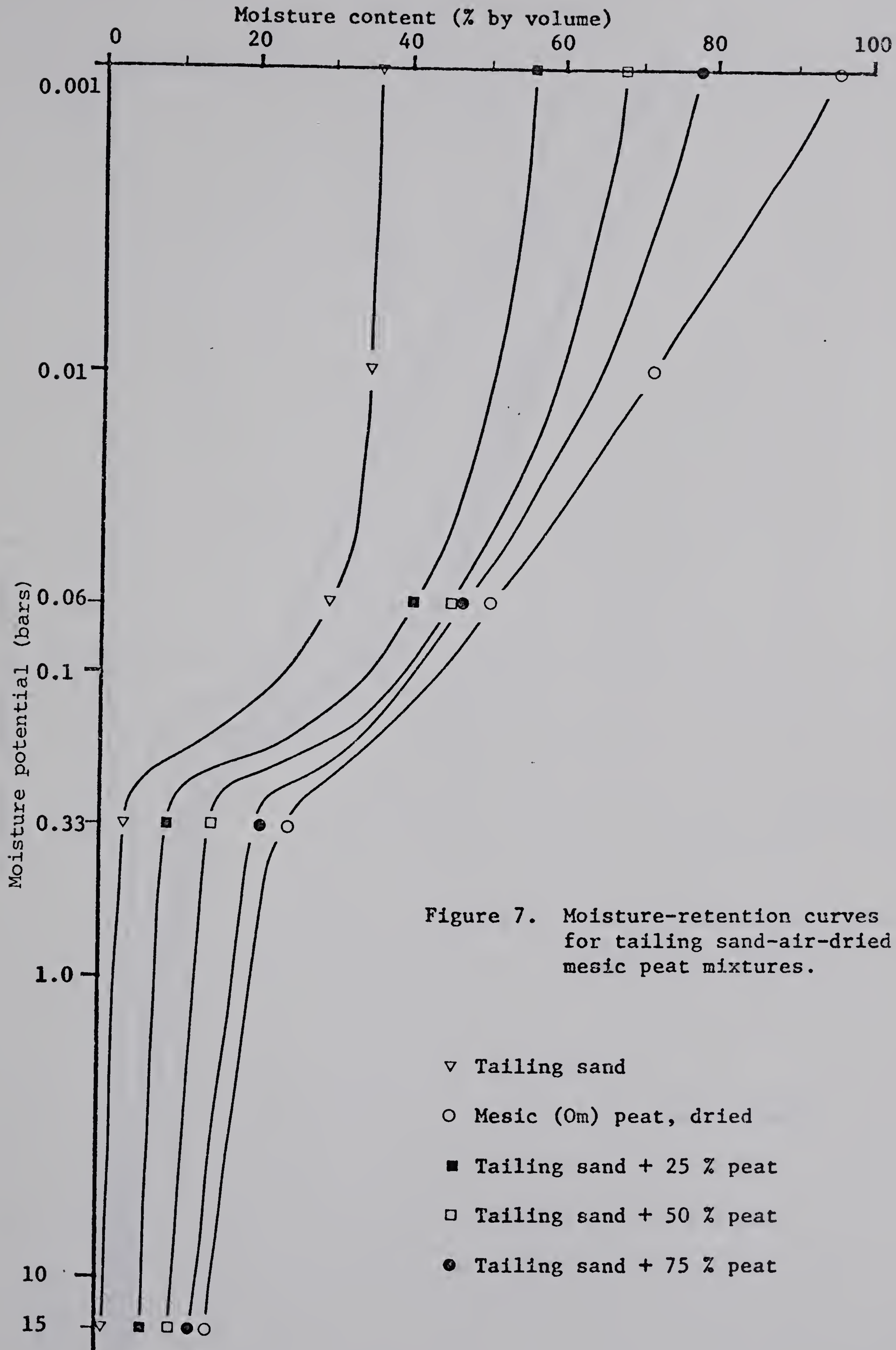


Figure 7. Moisture-retention curves for tailing sand-air-dried, mesic peat mixtures.

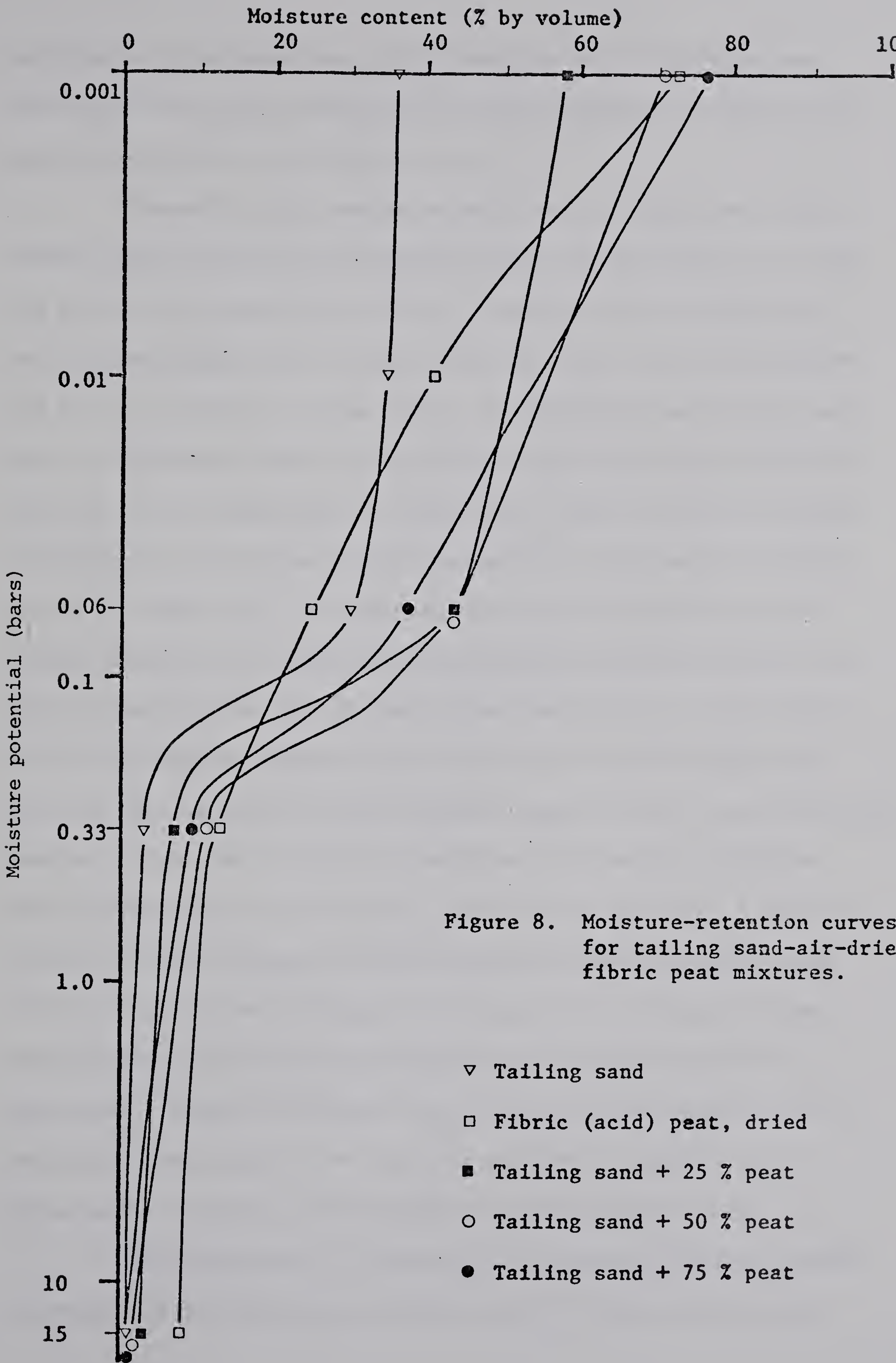


Figure 8. Moisture-retention curves for tailing sand-air-dried, fibric peat mixtures.

▽ Tailing sand

□ Fibric (acid) peat, dried

■ Tailing sand + 25 % peat

○ Tailing sand + 50 % peat

● Tailing sand + 75 % peat

enabling water to penetrate quickly into the soil. The slow re-wetting of dried peat particles should help maintain a high air porosity and therefore infiltration rate.

Generally, the results showed that peat additions to the tailing sand increased the available water storage capacity and that the greater the proportion of peat in the mixture, the greater was the increase (Table 24). Air-dried peat however, was less effective and was of no benefit in some cases. An important factor which must also be considered along with the proportion of peat mixed with tailing sand is the total amount of peat added (that is, the total depth of mixing). Both of these factors affect the total amount of water stored for plant use. For example, although the available water storage capacity of tailing sand (2 percent) is increased to 13 percent by the addition of moist mesic (Om) peat at a 1:1 ratio (Table 24) if this mixture comprises only the top 15 cm of the root zone (100 cm) the increase in total available water is from 2 cm to 3.65 cm. However, if the depth of this 1:1 mixture is 45 cm the available water storage capacity of the root zone becomes 6.95 cm. A note of interest on the influence of peat additions to tailing sand is the effect the 75 percent mesic peat additions had on available water. The available water for this peat-sand mix is double that of the peat alone. Figure 6 indicates that using this peat caused greater retention of moisture at low tensions relative to the pure peat, allowing more moisture to be retained in the available range.

Peat additions to tailing sand therefore influence moisture retention and porosity characteristics and through this moisture

conservation in general by (1) increasing total porosity and therefore infiltration (Satterlund, 1972), (2) increasing air porosity which also influences infiltration rates, with air-dried peat producing the greatest increases and (3) increasing the available water storage capacity when mesic peat, in particular, is used.

6.1.3 Buffering Capacity

Both tailing sand and fluvial sand are poorly buffered against change in pH (Figure 9) because of low clay and organic matter content (Table 10) and associated low cation-exchange capacity (Table 11). The addition of 5 me H^+/100 cc of tailing sand reduced its pH from 6.9 to 2.3 (some 4.6 pH units) creating an extremely acid soil. A similar treatment applied to the fluvial sand lowered its pH from 5.8 to 2.8 (3.0 pH units), again out of the optimum plant growth range. The slightly greater buffering capacity of the fluvial sand appears related to small differences in the above mentioned soil properties.

Peats generally have a high organic matter content and often are considered well buffered. However, there is considerable variation between the buffering capacities of the peats tested here (Figure 10). The fibric (Of) peat is poorly buffered as indicated by a 3.2 pH unit drop caused by the addition of 5 me H^+/100 cc of peat, a change of the same order of magnitude as that observed for the fluvial sand. The mesic (Om) peat has a greater buffering capacity and the addition of 5 me H^+/100 cc of peat decreased the pH

Figure 9. Buffering curves for tailing sand and fluvial sand.

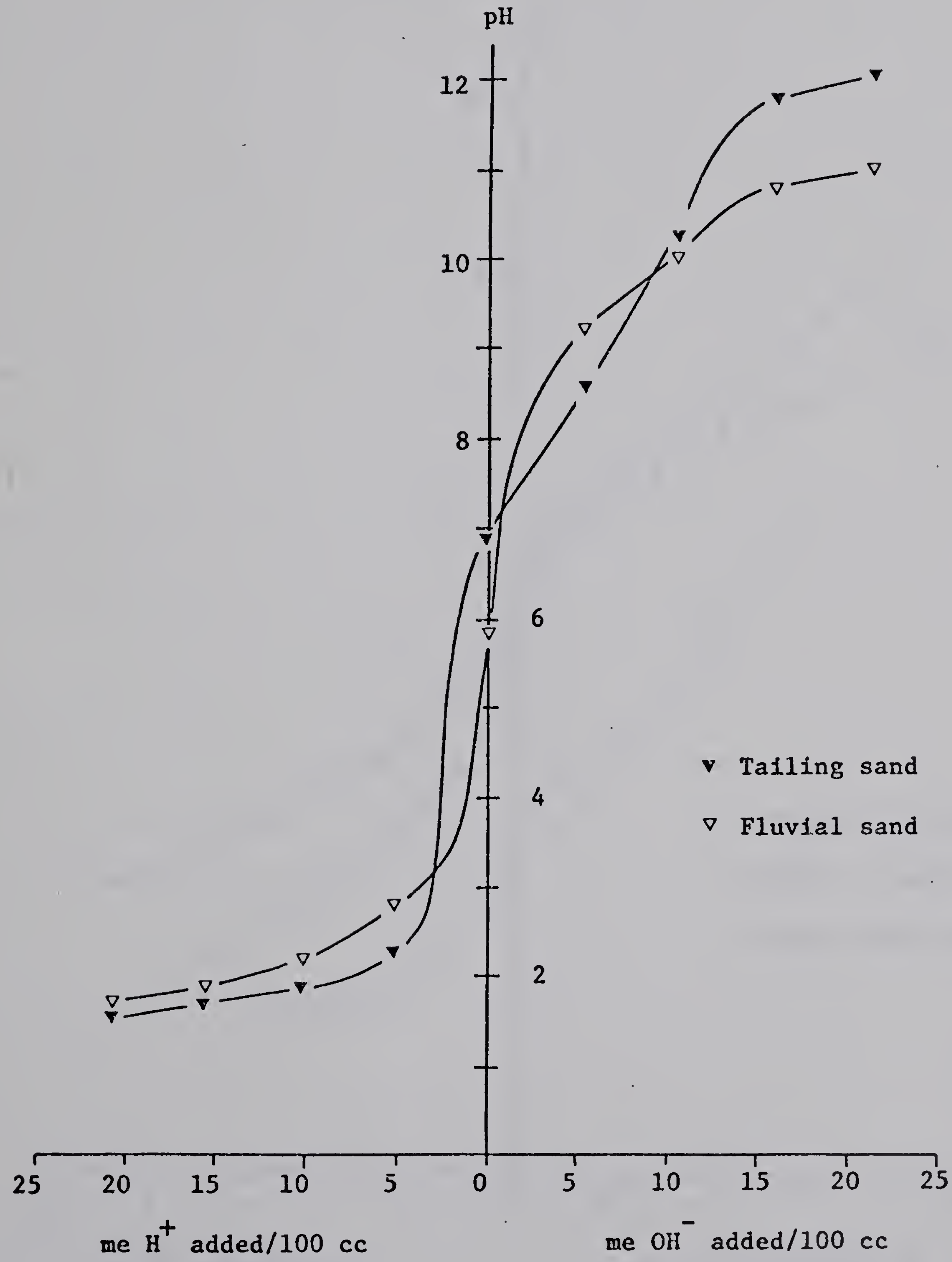
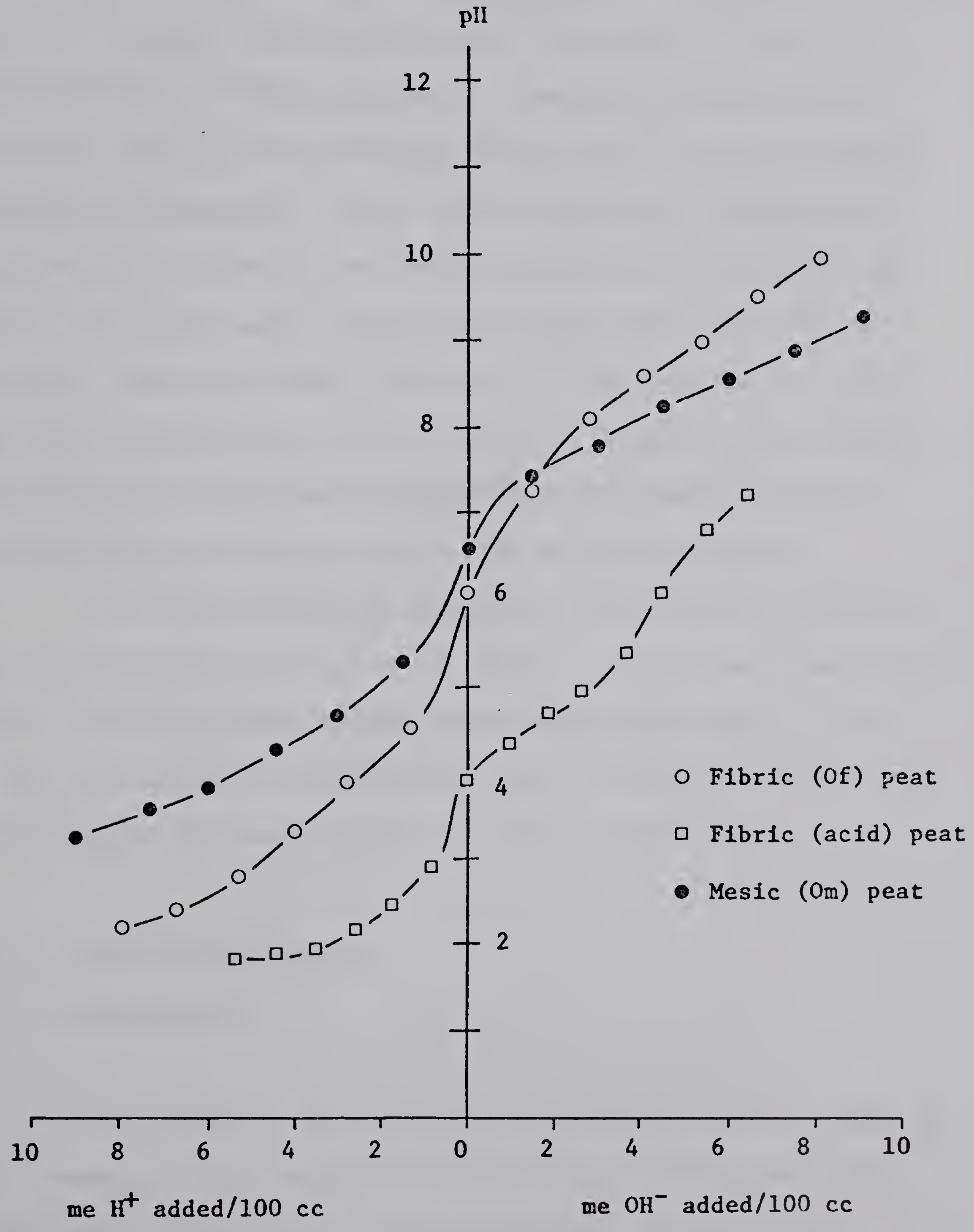


Figure 10. Buffering curves for the fibric (Of) peat, fibric (acid) peat and mesic (Om) peat.



from 6.6 to 4.1. The difference in the CEC between these two peats (Table 11) is an important factor in determining the buffering capacity.

The fibric (acid) peat is strongly buffered against a lowering of its natural pH (a drop of only 2.0 pH units is caused by addition of 5 me H^+/100 cc of peat). However, its natural pH is extremely acid (pH 3.9) indicating large amounts of active hydrogen. Analysis of exchangeable cations and CEC (Table 11) indicated that large amounts of undetermined cations contribute to the CEC of the fibric (acid) peat. The low pH suggests that this cation may be hydrogen. Therefore, small additions of H^+ have little effect on the total concentration of H^+ in this soil. Figure 10 also indicates that the fibric (acid) peat has less buffering capacity against a rise in pH above its natural level than do the other peats.

The results obtained from these measurements are consistent with those obtained by Takyi et al. (1977). Tailing sand (and fluvial sand) is poorly buffered against acidification which may be caused by SO_2 contamination or mineral fertilizer. Additions of mesic peat should improve the sand's ability to resist change in pH.

6.2.0 Greenhouse Experiment

6.2.1 Plant yields

The yields of the bromegrass-alfalfa crop given in Table 25 are a measure of the productivity of the peats, tailing sand and tailing sand-peat mixtures under three fertilization treatments.

Table 25. Dry weight yield of plant tops in the bromegrass-alfalfa crop on various soils under three treatments and the percent of total yield as bromegrass.

Soil material	Treatment	Total yield per pot* (g)	Percent of total yield as bromegrass**
Fibric (Of) peat	control	0.09 hi	40 ± 10
	fertilized	2.12 e	80 ± 1
	fertilized + limed	2.07 e	87 ± 3
Mesic (Om) peat	control	0.58 g	68 ± 1
	fertilized	3.02 ab	82 ± 4
	fertilized + limed	2.65 cd	86 ± 2
Fibric (acid) peat	control	0 i	0
	fertilized	0.08 hi	50 ± 5
	fertilized + limed	1.24 f	100 ± 0
Tailing sand	control	0.05 hi	22 ± 7
	fertilized	1.07 f	62 ± 3
	fertilized + limed	0.59 g	87 ± 7
Tailing sand + fibric (Of) peat	control	0.09 hi	32 ± 5
	fertilized	2.88 bc	78 ± 2
	fertilized + limed	2.38 de	80 ± 2
Tailing sand + mesic (Om) peat	control	0.34 gh	56 ± 6
	fertilized	3.22 a	80 ± 2
	fertilized + limed	2.71 bc	85 ± 3
Tailing sand + fibric (acid) peat	control	0.04 hi	50 ± 6
	fertilized	1.02 f	59 ± 1
	fertilized + limed	2.98 ab	83 ± 1
		$S\bar{x}$ = 0.1	

* yields not followed by the same letter are significantly different from each other at the 5 % level of significance as judged by Duncan's Multiple Range Test.

** mean of three replications is given along with the standard error of the mean ($S\bar{x}$).

The natural productivity of the tailing sand and all three peats, as indicated by the yields on the control (or nil fertilization) treatment was very low. The mesic (Om) peat produced significantly more plant matter than the other soil materials (Table 25). The fibric (acid) peat did not support growth of either bromegrass or alfalfa because of its extremely low pH (Table 11). Fertilization of the four individual soils resulted in significant yield increases in all except the fibric (acid) peat. The small response of the fibric (acid) peat indicates extreme acidity is likely the growth limiting factor. Lime added along with the fertilizer, at least partially corrected the acidity of this peat and the yield increased significantly (Table 25). The addition of lime and fertilizer to tailing sand and mesic (Om) peat depressed the yields relative to the fertilized treatments. However, in each case the lime plus fertilizer treatments resulted in greater yields than the control treatment.

The addition of peat alone to tailing sand did not significantly increase the yields on the tailing sand (Table 25 and Plate 2). Further treatment of the mixture with fertilizer (Plate 3) or fertilizer and lime (Plate 4) was necessary to produce significant yield increases. Yields from fertilized tailing sand-peat mixtures more than doubled those of the fertilized tailing sand where fibric (Of) and mesic (Om) peats had been added (Table 25). The tailing sand-fibric (acid) peat mix required the addition of lime as well as fertilizer to produce significant increases. Application of lime and fertilizer to the fibric (Of) peat-tailing sand and mesic

Plate 2.

Additions of peat alone to tailing sand (control treatment) did not significantly increase greenhouse yields of bromegrass-alfalfa crop at harvest, two months after seeding.
Note: acid peat = fibric (acid) peat,
decomp. peat = mesic (Om) peat
and raw peat = fibric (Of) peat.

Plate 3.

Fertilization of the tailing sand-peat mixtures greatly increased yields. The largest increase was with mesic (Om) peat (decomp. peat) followed by fibric (Of) peat, while the fibric (acid) peat-tailing sand mix was similar to the tailing sand.

Plate 4.

The addition of lime ($CaCO_3$) as well as fertilizer increased yields on the fibric (acid) peat-tailing sand mix to levels similar to the greatest obtained with the other peats, approximately three times the highest yields on the tailing sand. Fertilizer and lime additions depressed yields on tailing sand below those obtained on the fertilized treatment.

(Om) peat-tailing sand mixtures depressed yields significantly compared to the fertilized treatment.

The results in Table 25 indicate that additions of any of the three peats to tailing sand under correct management can almost triple the yields of the best pure tailing sand treatment. However, there is considerable variation in productivity with the type of peat added. Mesic (Om) peat mixed with tailing sand gives significantly greater yields than can be obtained using fibric (Of) peat. The best yield obtained with the fibric (acid) peat-tailing sand mix was not significantly different from that of the mesic peat-tailing sand mix. However, greater inputs specifically liming, were required to obtain this result.

The percentage of bromegrass in the bromegrass-alfalfa crop yields is also given in Table 25. Application of fertilizer consistently increased the proportion of bromegrass in the crop yield. Similarly, application of lime as well as fertilizer further increased the proportion of bromegrass. This was most striking in the case of the fibric (acid) peat where no alfalfa survived in the fertilized plus limed treatment. This result contrasts with the tentative conclusion of Takyi et al. (1977) that liming sand-peat mixes to a near neutral pH would be necessary to promote good growth of legumes.

Observations at harvest indicated that no nodules had formed on the alfalfa roots when fertilizer was applied, although they were present in the control treatments of all soil materials except the fibric (acid) peat. These results are consistent with the general observation that fertilization of grass-legume mixtures

favors production of the grass portion and reduces the occurrence of nitrogen fixing nodules on the roots of legumes (Black, 1968; Takyi et al., 1977).

Observations made on the percent of seeds germinating in the greenhouse (Appendix 2) showed that bromegrass germination was over 80 percent for all soils. Alfalfa germination was also over 80 percent, with two noteable exceptions: the fibric (acid) peat control treatment and the tailing sand fertilizer plus lime treatment. Both soils were re-seeded, however, germination remained poor and therefore reduced plant yields.

6.2.2 Mineral Nitrogen Status in the Greenhouse Soils

Mineral nitrogen levels in all soil materials were initially very low (Table 26). The tailing sand had no measurable amount of mineral nitrogen and addition of peat to tailing sand produced only slight increases. The somewhat greater amounts of mineral nitrogen found in the fibric (acid) peat may have been a result of disturbance and drainage of this peat in the field prior to sampling. These actions could cause some mineralization of the organic nitrogen (as discussed in section 3.0). Initial analysis also indicated that NH_4-N and NO_3-N were present in almost equal amounts in all materials.

Nitrification of applied nitrogen is an important feature in all the soils examined, including the tailing sand-peat mixes (Table 27). It is interesting to note that nitrification did not occur in the fibric (acid) peat nor in mixtures of this peat and

Table 26. Initial mineral nitrogen status of materials used in the greenhouse experiment.

Soil material	Milligrams of nitrogen per pot			Air-dry soil per pot (g)*
	NH_4-N	NO_3-N	total mineral N	
Fibric (Of) peat	2.2	1.5	3.7	180
Mesic (Om) peat	3.4	2.3	5.7	90
Fibric (acid) peat	4.9	2.9	7.8	120
Tailing sand	0	0	0	1500
Tailing sand + fibric (Of) peat	1.1	0.8	1.9	885
Tailing sand + mesic (Om) peat	1.7	1.2	2.9	880
Tailing sand + fibric (acid) peat	3.3	1.9	5.2	880

* this column allows conversion of nitrogen content to parts per million (ppm).

Table 27. Mineral nitrogen content of soil materials at harvest. (Air-dried weight of soil material per pot is given in Table 26, allowing conversion to parts per million.)

Soil material	Treatment*	Milligrams of N/pot NH_4-N	NO_3-N	total mineral N	Percent of applied N remaining as mineral N
Fibric (Of) peat	control	0.6	0.1	0.8	-
	fertilized	22.6	31.4	54.0	31
	fertilized + limed	1.8	31.4	32.8	19
Mesic (Om) peat	control	0.5	1.8	2.3	-
	fertilized	3.4	28.6	32.0	19
	fertilized + limed	1.0	30.1	31.1	18
Fibric (acid) peat	control	0.2	0.1	0.3	-
	fertilized	53.3	50.1	105	61
	fertilized + limed	24.0	55.6	79.6	46
Tailing sand	control	0	0	0	-
	fertilized	48.9	83.0	132	76
	fertilized + limed	0.8	133	134	78
Tailing sand + fibric (Of) peat	control	0.4	0	0.4	-
	fertilized	11.0	43.4	54.3	31
	fertilized + limed	1.2	51.0	52.2	30
Tailing sand + mesic (Om) peat	control	0.6	1.4	2.0	-
	fertilized	2.8	26.2	29.0	17
	fertilized + limed	1.0	53.4	54.4	32
Tailing sand + fibric (acid) peat	control	1.1	0	1.1	-
	fertilized	78.4	55.3	134	78
	fertilized + limed	0	54.2	54.2	31

* total applied nitrogen (as NH_4NO_3) on fertilized and fertilized + limed treatments was 173 mg N per pot (168 kg/ha).

tailing sand unless lime was added along with nitrogen fertilizer. However, liming of this peat is necessary for optimum plant productivity (Table 25). Both plant growth and nitrification appear to be limited by the extreme acidity of this peat. Liming also increased nitrification in all other soil materials tested. Because of potential leaching losses of NO_3-N rapid nitrification is an undesirable soil process. The rapid hydraulic conductivities of the peats and tailing sand (Table 22) indicate that leaching of NO_3-N is potentially a serious problem.

The percentage of applied nitrogen remaining in the soil at harvest was largely a function of plant growth. Because of the wide range in yields (Table 25) the amounts of nitrogen remaining also varied considerably (Table 27). The four treatments which had the lowest yields also had the highest amounts of applied nitrogen remaining, over 60 percent in each case. Lack of available nitrogen or other major nutrients was not the growth limiting factor for these soils. The lowest percentages of applied nitrogen remained in the mesic (Om) peat and tailing sand-mesic (Om) peat mixes, both of which produced high yields. Addition of lime improved nitrogen uptake in the two soil materials in which it improved yields, the fibric (acid) peat and tailing sand plus fibric (acid) peat. Otherwise, liming had an insignificant or detrimental effect.

The combination of large amounts of nitrogen remaining unused plus rapid nitrification and high hydraulic conductivities could potentially result in significant losses of NO_3-N by leaching. Nitrification was found to be high in all of the highest plant

yielding treatments. However, the mesic (Om) peat showed the highest utilization of applied nitrogen, leaving the least amount available to be lost through leaching.

6.2.3 Influences of Fertilizer Treatments on Soil pH

Soil pH values decreased with application of fertilizer in all soil materials except the tailing sand-fibric (acid) peat mixture (Table 28). The magnitude of the acidification varied between soil materials, from a 2.2 pH unit drop in the tailing sand to a 0.4 unit drop in the fibric (acid) peat. Two factors appear to control the degree of acidification in each soil material: first, the buffering capacity of the material and secondly, the degree of nitrification which the material undergoes. Other factors may also contribute to acid production but it is assumed that nitrification is the main contributor. Nitrification of NH_4-N produces NO_3-N and hydrogen ions which decrease the soil pH. The tailing sand is poorly buffered (section 6.1.3) and results in Table 27 indicate that large amounts of NH_4-N were nitrified. This combination resulted in the large drop in pH. The fibric (acid) peat was found to be strongly buffered against further acidification (Figure 10). Also, results in Table 27 indicate that no nitrification occurred in this peat and the pH changed only slightly. There was no drop in the pH of the fibric (acid) peat-tailing sand mix. Less acidification occurred in the mesic (Om) peat than the fibric (Of) peat although nitrification appeared stronger in the former peat. The mesic (Om) peat

Table 28. The pH of soil materials after two months with three treatments applied to a bromegrass-alfalfa crop.

Soil material	Treatment*		
	control	fertilized	fertilized + limed
Fibric (Of) peat	6.1	5.3	7.5
Mesic (Om) peat	6.5	5.9	7.5
Fibric (acid) peat	4.2	3.8	6.9
Tailing sand	7.8	5.6	7.3
Tailing sand + fibric (Of) peat	6.6	5.5	7.7
Tailing sand + mesic (Om) peat	6.7	5.9	7.6
Tailing sand + fibric (acid) peat	4.3	4.3	7.5

* values are means of three replications. The range between replicates for any soil was less than 0.1 pH unit.

therefore, is better buffered against acidification than the fibric (Of) peat confirming findings in Figure 10. Similar results were obtained in mixes of these two peats with tailing sand.

Application of lime as well as fertilizer resulted in pH values above the control treatment levels in all soil materials except the tailing sand. Based on a lime equivalent of 62 kg $CaCO_3$ per 100 kg NH_4NO_3 (Neilsen, 1971) the acidifying capacity of 168 kg N/ha would be neutralized by 104 kg $CaCO_3$/ha. Therefore the lower pH on the lime plus fertilizer treatment of tailing sand (compared to the control) must be due to a combination of factors and not just nitrification since $CaCO_3$ had been applied at 4.5 tonnes/ha. The various liming rates used on other materials were sufficient to maintain pH values in the near neutral to slightly alkaline range over the length of the experiment.

6.3.0 Field Experiments

6.3.1 Runoff Plot

Although studied for only two seasons, the runoff plot was useful in showing the magnitude of erosion and indicating some of the factors influencing the erodibility of different surface treatments.

Rainfall measurements were made three times at the runoff plot between August 17 and October 9, 1975, as shown in Table 29. These measurements although infrequent, allowed general observations to be made about the erodibility of the plot materials. The importance of rainfall intensity on runoff was also observed as total

Table 29. Percent of rainfall lost as runoff and kilograms of soil lost per hectare from both replications of the four treatments on the runoff plot in 1975.*

Time period	Precipitation (mm)	Treatment**							
		Tailing sand control		Fibric peat mulch		Mesic peat mulch		Mesic peat mixed-in	
		Rep.1	Rep.2	Rep.1	Rep.2	Rep.1	Rep.2	Rep.1	Rep.2
August 17 to August 26	16	4.03	0	0.17	0	0	0	0	0
		(1920)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
August 26 to September 18	88	-	-	-	0.09	-	0	-	0.09
		-	(48100)	-	(0)	-	(0)	-	(0)
September 25 to October 9	36	-	3.14	-	0	-	0	0	0.07
		-	(1600)	-	(0)	-	(0)	(0)	(0)

* included are only those periods between August 17 and October 15 in which there was runoff.

** in each case the upper number is the percent rainfall lost as runoff, while the lower number (in parentheses) is the air-dry soil lost (kg/ha).

\- indicates runoff not collected because of damage to plot.

rainfall during a measurement period appeared unrelated to percent rainfall lost as runoff (Table 29). For example, although the August 16 to 26 period had less than half the rainfall of the September 25 to October 9 period, runoff and erosion appeared to be of a similar magnitude. Water lost as runoff is lost to plant use and in a moisture deficit region (Table 30) this factor may influence plant growth.

Daily rainfall measurements were obtained courtesy of GCOS, Ltd. (Appendix 3). These data show the large number of individual storms which produced the total rainfall for each period measured at the runoff plot. The data suggested more frequent measurement of rainfall was necessary.

An interesting note here was the large rainfall on July 13, 1975, which was recorded by GCOS, Ltd. at 74.9 mm in 24 h (Appendix 3). This rainfall occurred while the runoff plot was initially being set up and the plot site consisted of recently contoured tailing sand. Severe gully erosion developed both at the plot site and at other locations on the dyke. The erosion delayed set-up of the runoff plot until the plot site could be re-contoured with heavy equipment.[1]

According to the data shown in Table 31 a storm of 74 mm in 24 h has a return period of about 25 years in the Fort McMurray area. Toogood (1977) suggests that the rainfall intensities in Alberta might actually be higher than those based on limited official

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[1]Footnote: the prompt assistance from GCOS, Ltd. is gratefully acknowledged.

Table 30. Meteorological and moisture deficit characteristics of the Fort McMurray area adapted from Laycock, 1964 and based on data from 1921 to 1950.

Meteorological characteristic	Value for the Fort McMurray area
Average annual precipitation	390 mm
Average potential evapotranspiration*	470 mm
Average moisture deficit (102 mm storage)	117 mm
Average moisture deficit (305 mm storage)	56 mm
Maximum moisture deficit (102 mm storage)	213 mm
Minimum moisture deficit (102 mm storage)	0
Percent of years with no deficit (305 mm storage)	24 %
Percent of years with over 200 mm deficit (305 mm storage)	12 %
Percent of years with over 200 mm deficit (102 mm storage)	12 %
Percent of years with over 200 mm deficit (13 mm storage)	35 %

* potential evapotranspiration calculated using Thornthwaite procedures.

meteorological records.

The percent of rainfall lost as runoff on the plot treatments varied considerably (Table 29) with tailing sand showing the greatest losses over four percent of the rainfall received. The

Table 31. Rainfall intensity; duration frequency data for the Fort McMurray area as adapted from Bruce, 1968.

Return period (years)	Maximum rainfall (in mm) per time period				
	24 h	1 h	30 min	10 min	5 min
2	-	-	-	5	4
5	-	-	-	7	5
10	-	-	-	10	7
25	74	20	15	12	10

- indicates data not available.

runoff losses on the treatments where peat had been applied, either as a mulch or mixed-in were very small with the mixed-in treatment having slightly greater loss over the 1975 measurement period.

Soil losses occurred only on the tailing sand treatment and these were severe. During the period from August 26 to September 18, 1975 some 48 tonnes/ha of soil was lost.

In 1976, rainfall measurements were made at the runoff plot from May 28 until September 16 (Table 32). Daily rainfall records were again obtained from GCOS, Ltd. (Appendix 3). Of the seventeen measurement periods through the summer, runoff losses and soil

Table 32. Rainfall measurements at the runoff plot from May 28 to September 8, 1976.

Measurement period	Rainfall (mm)
May 28 to June 9	2
June 9 to June 15	7
June 15 to June 23	1
June 23 to June 24	10
June 24 to June 30	15
June 30 to July 8*	10
July 8 to July 14	34
July 14 to July 16	3
July 16 to July 21	8
July 21 to July 28	15
July 28 to Aug 4	1
Aug 4 to Aug 11	1
Aug 11 to Aug 17*	24
Aug 17 to Aug 19	0
Aug 19 to Aug 27	53
Aug 27 to Sept 8	41
Sept 8 to Sept 16	0
May 28 to Sept 16	total: 225

* indicates periods during which runoff was produced on at least one plot treatment.

erosion occurred in only two periods (Table 33). It is interesting to note that these two periods did not have the largest total rainfall per measurement period nor did they have the highest 24 h rainfalls. The two largest 24 h storms (August 26 and September 6) did not produce any erosion, a factor which implies that 24 h rainfall

Table 33. Percent of rainfall lost as runoff and kilograms of soil lost per hectare from the runoff plots in 1976.*

Time period	Precipitation (mm)	Treatment**			
		Tailing sand control	Fibric peat mulch	Mesic peat mulch	Mesic peat mixed-in
June 30 to July 8	10	5.27 (1150)	0 (0)	0 (0)	5.27 (278)
August 11 to August 17	25	17.6 (7750)	0 (0)	0.01 (0)	15.1 (276)

* included are only those periods between May 28 and September 16, 1976 in which there was runoff produced on any treatment.

** in each case the upper number is the percent rainfall lost as runoff, while the lower bracketed number is the air-dry soil lost in kg/ha.

intensities do not correlate highly with runoff and soil erosion. Toogood (1963) suggested 15 min intensities are better related to soil losses.

The data collected from the rainfall intensity recording gauge (Table 34) although not complete (due to mechanical problems)

Table 34. Rainfall intensities for various durations of several rainfall counts as recorded at the runoff plot during 1976. Note that due to equipment failure several rainfalls were not recorded.

Date of event	Rainfall (mm) per time period				
	24 h	1 h	30 min	10 min	5 min
June 9	-	-	-	2	1
June 10 - 15:					
(i)	-	4	3	1	1
(ii)	-	-	-	-	1
(iii)	-	-	-	-	1
June 17 - 23	-	-	-	1	<1
June 23 - 30:					
(i)	11	3	2	1	1
(ii)	-	-	1	<1	<1
(iii)	-	-	-	1	1
(iv)	-	-	2	1	1
(v)	-	-	-	1	<1
June 30 - July 8 (estimated)	10*				
July 8 - 14:					
(i)	7	3	2	1	1
(ii)	-	3	2	1	<1
(iii)	-	-	2	1	1
(iv)	-	-	-	2	1
July 14 - 16	-	3	3	2	2
July 16 - 21:					
(i)	-	3	2	1	1
(ii)	4	3	3	2	2
July 21 - 28:					
(i)	4	2	2	1	1
(ii)	-	-	-	1	<1
(iii)	-	-	-	1	<1
(iv)	-	2	1	1	<1
(v)	4	1	1	1	1
July 28 - Aug 4	-	-	-	-	1
Aug 6 - 11	-	-	-	1	<1
Aug 11 - 17	25*	20	15	6	3
Aug 19 - 27	54	9	5	2	1
Aug 27 - Sept 8	17	6	3	2	1

* indicates rainfall which produced runoff on one or more treatments on the runoff plot.

show the intensity and duration characteristics of a number of storms. Most rainfall events (storms) are of a short duration (less than 1 h) and of low intensity (less than 5 mm/h).

Two storms which were recorded show dramatically the effect of rainfall intensity on runoff and soil erosion. A storm on August 13, 1976 dropped 25 mm of rain at the runoff plot in 24 h while a storm on August 26, 1976, dropped 54 mm in 24 h (Table 34). However, the higher 5, 10, 30 min and 1 h intensities resulted in the former event producing runoff and erosion on two treatments (Table 33). The larger 24 h storm (but of lower intensity) was totally absorbed by the soil on all plot treatments. Figure 11 derived from the field recorder charts shows the cumulative rainfall of these two storms. Figure 12 re-arranges the same data to show the differences in intensity and duration between the two storms. It is interesting to note that both the 30 min and 1 h rainfall intensities of the August 13 storm equalled the 25-year return period rainfall for the Fort McMurray area (Table 31). The 10 min rainfall intensity of this storm exceeded the 2-year return period rainfall but was less than the 5-year. Runoff and soil erosion in Alberta have been postulated to correlate more closely with 10 and 15 min rainfall intensities (Toogood, 1963). Therefore, a storm of similar intensity and potential erodibility may be expected every 2 to 4 years.

The effect of the plot treatments on runoff and soil erosion (Table 33) deserves further attention. Soil loss was greatest on the tailing sand control plot (9 tonnes/ha for the 1976 season). No soil was lost from the two treatments where peat was applied as

Figure 11. Cumulative rainfall graphs for two rainfall events in August, 1976. Accumulated rainfall is plotted at 0.5 h intervals for the duration of the storms from data obtained with the rainfall-intensity recording gauge. Runoff and soil loss were generated only by the August 13 event.

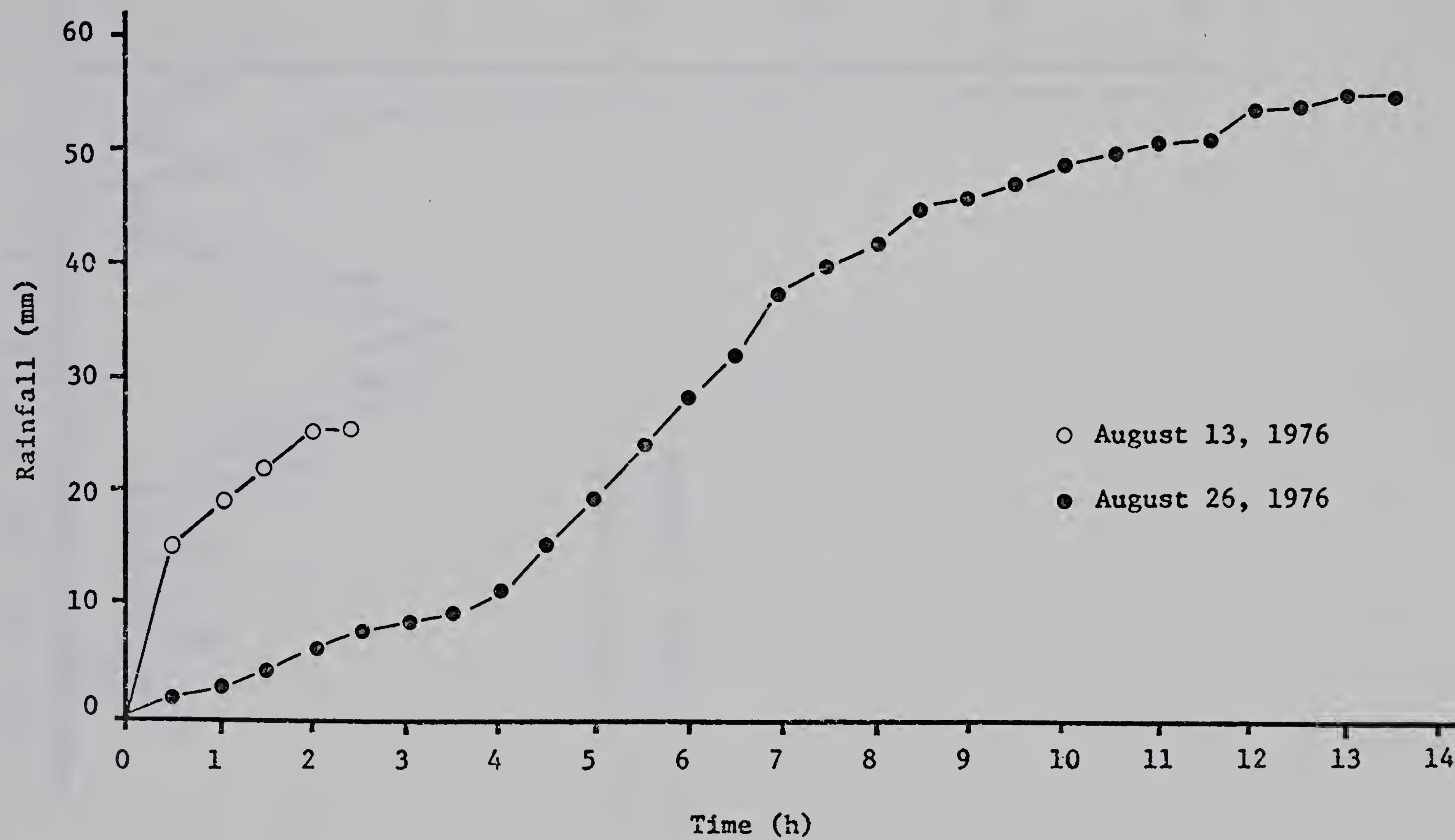
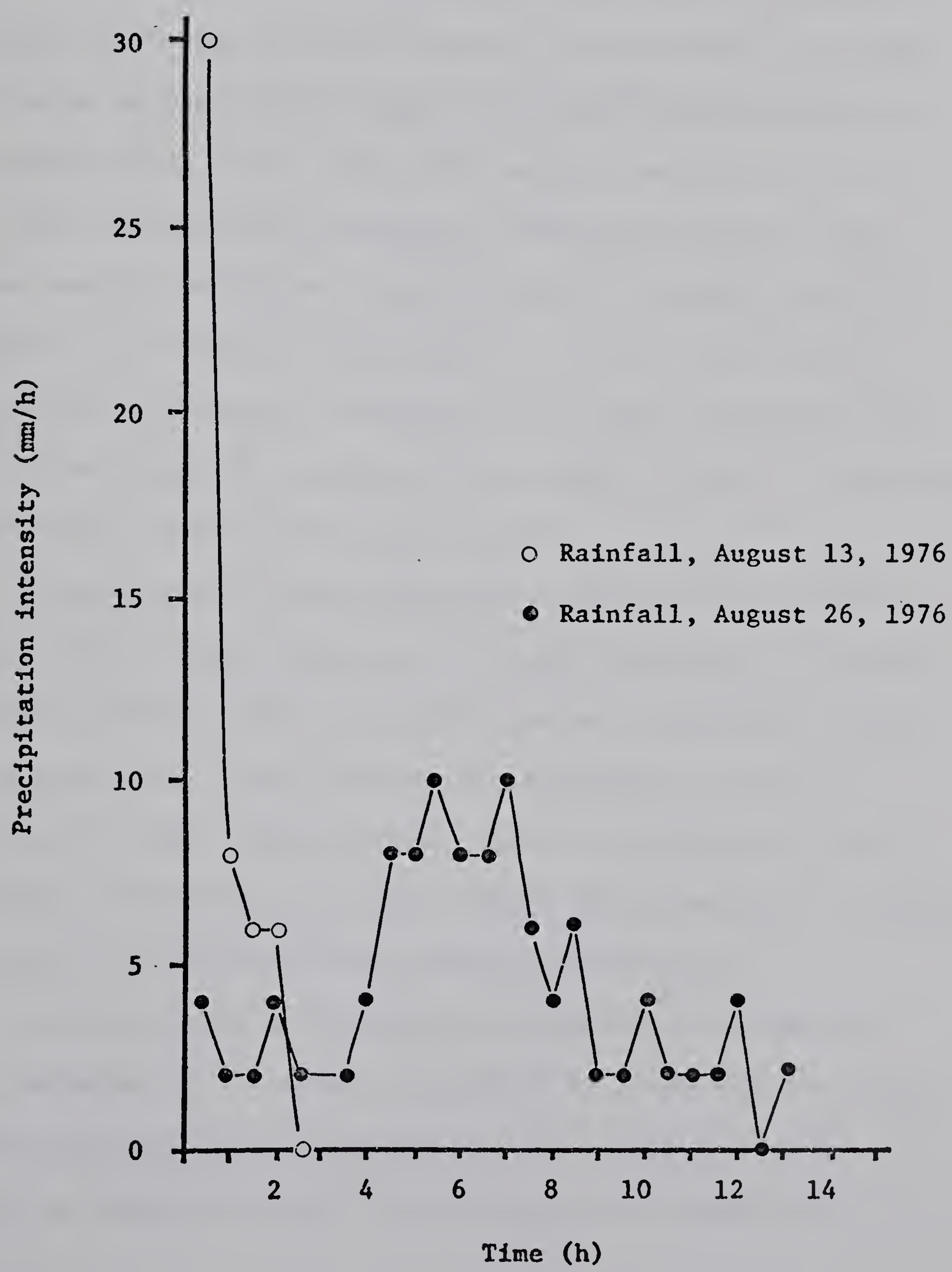


Figure 12. Rainfall intensity and duration (at 30 min intervals) of 2 rainfall events recorded at the runoff plot in August, 1976. Data based on Figure 11.



a mulch, nor from the mixed-in peat application. The generally lower soil losses in 1976 compared to 1975 may have resulted due to less erosive rainfall and also to the increased vegetative cover on all treatments. Losses of water as runoff however, were high on the mixed-in peat treatment and the tailing sand. The water losses on these two treatments from the August 13 storm were particularly significant since almost 5 mm of rain was lost as runoff. The high loss of water on the mixed-in, mesic (stockpiled) peat treatment was not accompanied, as in the case of the tailing sand, by a loss of soil. This suggests that although the infiltration rate on this treatment was not sufficient to take up all the rainfall, the peat did prevent the erosion of large amounts of soil. This is consistent with the findings of Lattanzi et al. (1974) and Meyer et al. (1972) who attribute the reduced soil loss under a mulch to decreased splash erosion and decreased runoff velocity.

The results of these measurements point to two important problems: first, that tailing sand is highly erodible by water and second, that surface runoff of rainfall can be a significant factor on tailing sand even where peat has been mixed-into the sand. Application of either fibric or mesic peat as a mulch greatly reduced losses of both water and soil. While mixing peat into the sand reduced soil losses, water runoff remained fairly high.

Reduced runoff as obtained by the peat mulch treatments serves two purposes. It conserves moisture by increasing the amount of water infiltrating and recharging the soil moisture storage capacity, an important factor in a moisture deficit area and it

reduces the potential for water erosion.

6.3.2 Infiltration Measurements

Figure 13 shows the results of the infiltration measurements. Moisture contents of the soil profiles (Table 35) indicate

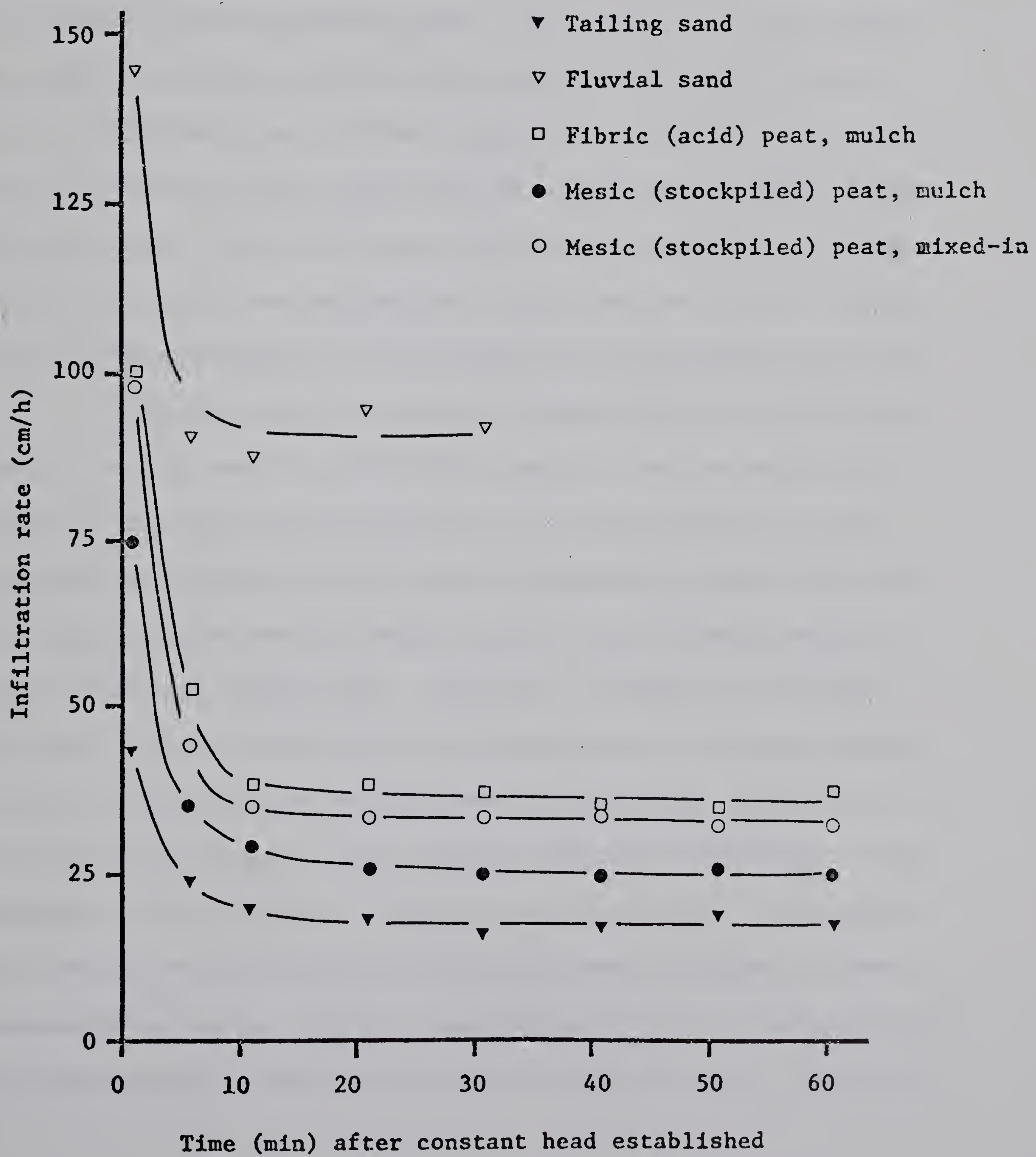
Table 35. Soil moisture content* at four depths at the time of infiltration rate determinations.

Depth (cm)	Tailing sand control	Fibric peat mulch	Mesic peat mulch	Mesic peat mixed-in	Fluvial sand
0 - 15	3.2	3.0	3.5	4.7	9.7
15 - 30	4.5	2.7	1.6	1.4	9.1
30 - 60	7.7	4.3	3.7	4.1	6.1
60 - 90	8.1	6.8	6.6	6.5	7.8

* volumetric moisture percent based on gravimetric samples and measured bulk density of each depth (Tables 12 and 18).

that the soils were fairly dry at the time measurements were made. The tailing sand treatment showed a rapid initial infiltration rate which quickly decreased to a constant infiltration rate of about 17 cm/h. This rate is high relative to most mineral soils, reflecting the sand texture of the tailings. The fluvial sand by comparison had an extremely rapid infiltration rate which levelled off to just under 100 cm/h, a value similar to the saturated hydraulic

Figure 13. Infiltration rates of the treatments on the runoff plot and of fluvial sand at an undisturbed site.



conductivity of this material as measured in the laboratory (Table 22).

Application of peat to the tailing sand affects infiltration by greatly increasing the initial infiltration rate and by increasing the constant rate portion of the infiltration curves (that is, the infiltration rate between 11 and 61 min after measurements commenced).

All three peat applications to the tailing sand significantly increased the infiltration rate. The fibric (acid) peat applied as a mulch resulted in significantly higher infiltration than the mesic (stockpiled) peat similarly applied. The greater total porosity and air porosity in the fibric peat allow more rapid uptake of water. Mixing-in mesic (stockpiled) peat resulted in a significantly higher infiltration rate than application of this peat as a mulch. Differences in the wettability of the surfaces may have caused this result.

Although these measurements indicate that the infiltration rate of tailing sand is sufficient to handle even the most severe storms occurring in the area (Table 31), runoff occurred on this treatment as a result of relatively low intensity storms (Table 33). This apparent discrepancy results from the use of ponded water to measure the infiltration rate. Using the concentric ring method important factors influencing infiltration such as raindrop splash erosion, surface sealing and the effect of slope are eliminated. Observations at the plot also indicated that the wettability of the materials on the different treatments varied greatly. The method of infiltration rate determination used here does not appear to have measured this factor. However, application of peat to the surface of the sand greatly increases the initial infiltration rate. Peat also

may become unwettable upon air-drying (Allison, 1973). However, very little soil or water was lost from the treatments where peat was applied to the surface (Table 33).

6.3.3 Wettability Measurements

Wettability varied greatly between soil materials and particularly with depth in the tailing sand (Table 36). The surface of the tailing sand treatment (to a depth of approximately 0.5 cm) of the runoff plot (and similar samples from adjacent areas on the dyke) was found to be readily wetted, despite the high sand-size fraction (Table 17). However, below this surface layer at a depth of from 0.1 to 0.5 cm the tailing sand became water repellant (Scholl, 1975). At greater depths (100 to 130 cm) the degree of water repellancy increased further. In terms of infiltration, the data indicate that the top 0.5 cm of tailing sand can readily absorb rainfall. However, because infiltration into dry, water repellant soil is slow (Debano, 1975) the tailing sand below this layer takes up the water much more slowly (assuming it is air-dry). This produces a situation which may lead to the surface 0.5 cm of sand becoming saturated and flowing downslope over the repellent layer. Approximately 0.2 cm of rainfall would be necessary to saturate the top 0.5 cm layer of tailing sand.

The wettability of the tailing sand appears to be related to the residual hydrocarbons remaining after the oil extraction processing. Water repellancy in other soils has been found related to

Table 36. Wettability of various air-dried materials as measured by the time for water drop infiltration. Results are the mean values of twelve replications.

Soil material	Location of test	Time for drop infiltration (s)*
Tailing sand (undisturbed surface)	field	1 d
Tailing sand (2 to 5 mm below surface)	field	63 b
Tailing sand (bulk sample from 1.0 to 1.3 m)	lab	238 a
Fluvial sand (bulk sample from 0 to 15 cm)	lab	1 d
Fibric (acid) peat (mulch)	field	30 c
Mesic (stockpiled) peat (mulch)	field	43 c
Mesic (stockpiled) peat (mixed-in)	field	6 d
	$S\bar{x}$ = 6.19**	

* treatments not followed by the same letter are significantly different from each other at the 5 % level of significance as judged by Duncan's Multiple Range Test. Values are the means of twelve replications.

** standard error of the mean.

aliphatic hydrocarbons from plant sources (Savage et al., 1972). Takyi et al. (1977) reported that tailing sand contains 0.14 percent methylene chloride extractable hydrocarbons. A breakdown of this residue is assumed to be the reason for the wettability of the surface layer of tailing sand. Textural differences (Table 18) between sand layers were too slight to have affected the wettability to any significant degree.

Unlike the tailing sand, the surface 15 cm of the fluvial sand readily absorbed water (Table 30). This allows rapid infiltration and reduces erosion potential.

Application of peat as a mulch resulted in a surface significantly less wettable than the surface layer of tailing sand but significantly more wettable than the subsurface tailing sand. Fibric (acid) peat and mesic (stockpiled) peat had similar effects. Mixing peat into the tailing sand results in a less repellant surface than peat application as a mulch. However, observations indicated that the mulch peat protects the surface against splash erosion and quickly absorbs raindrops. Similarly, water drops released from 30 cm above the peat were absorbed into the peat. The high fiber content, pore space and air porosity contribute to this absorption capability. Rainfall or waterdrops hitting bare tailing sand (on either the tailing sand treatment or in sand patches where the mesic peat was mixed into the tailing sand) caused sand to be eroded by the splash, and left the surface "pitted" even after light rainfalls (Plate 5).

Wettability of the soil surface therefore has an important influence on infiltration rate and therefore also on moisture

Plate 5.

Surface of the tailing sand treatment of the runoff plot showing the "pitting" caused by raindrops. A surface mulch of peat serves to absorb raindrop impact energy and reduce splash erosion. Diameter of lense cap is 6 cm.

conservation and erodibility.

6.3.4 Field Plant Yields

Yields of the oat cover crop grown on the runoff plot in the fall of 1975 are given in Table 37. The oat plants were harvested while green, prior to heading-out. The yields were lowest on the

Table 37. Yields of green cover crop (oats) on the runoff plot treatments harvested in October, 1975 after two months growth. Yields expressed as ovendried (70 C) weights.

Treatment	Yield (kg/ha)*
Tailing sand (control)	517 ± 1
Fibric (acid) peat, mulch	852 ± 161
Mesic (stockpiled) peat, mulch	979 ± 421
Mesic (stockpiled) peat, mixed-in	1230 ± 87

* mean yield of two replications and the standard deviation. Note that the large standard deviation for the mesic peat mulch treatment resulted from damage and reduced yield on one replication due to large scale erosion on the dyke.

tailing sand treatment and the oat plants on this treatment were observed to be both fewer in number and smaller in size than on the other treatments. The plants on the tailing sand treatment were slightly yellower than adjacent plots, possibly indicating a nutrient deficiency, although all treatments received the same large amounts

of fertilizer. Yields of the cover crop increased greatly when peat was applied, regardless of the type of peat or method of application. Plants on the peat treatments were more densely spaced, darker green in colour, wider leafed and taller than those on the tailing sand. The height of the oat cover on the tailing sand was about 25 to 30 cm, while on the fibric (acid) peat treatment the height was between 30 and 35 cm and between 35 and 40 cm on the two treatments where mesic (stockpiled) peat was applied. The mesic (stockpiled) peat gave higher yields than the fibric (acid) peat although the latter had been limed in addition to the general fertilization all treatments received. The mixed-in application of mesic (stockpiled) peat gave an average yield higher than the mulch application of this peat. However, one replication of the mulched mesic peat was severely damaged, bringing down its average yield (and increasing the standard deviation). Yields on the undamaged mesic (stockpiled) peat mulch treatment were similar to those on the mixed-in treatment. Therefore, method of peat application does not appear to have significantly influenced yields of the cover crop. It was also noticed at this time that the upper roots of some plants in the tailing sand treatment had been exposed due to erosion of the sand. This was not observed on the other treatments where peat had been applied.

The 1976 harvests of the perennial grass-legume crop on the runoff plot are given in Table 38. The July yields show that the tailing sand (control) treatment again had the lowest productivity. The application of peat to tailing sand increased the yields, with the mesic (stockpiled) peat having higher yields than the fibric (acid)

Table 38. Dry weight yields of grass, alfalfa and combined total for two cuttings (July 15 and September 8) on the runoff plot treatments in 1976.

Treatments	July yields (kg/ha)*			September yields (kg/ha)*			Season's total yield (kg/ha)*		
	grasses	alfalfa	Total	grasses	alfalfa	Total	grasses	alfalfa	Total
Tailing sand (control)	392	8	400	1656	24	1680	2048	32	2080
Fibric (acid) peat, mulch	469	0	469	1240	0	1240	1709	0	1709
Mesic (stockpiled) peat, mulch	856	4	860	1748	12	1760	2604	16	2620
Mesic (stockpiled) peat, mixed-in	710	14	724	1576	24	1600	2286	38	2324

* mean dry weight (70 C) yield of four quadrats (50 x 50 cm) taken from each treatment of replication 2.

peat. The mesic (stockpiled) peat mulch treatment out-yielded the same peat mixed into the tailing sand. Alfalfa made up a very small percentage of the yield on all treatments and was totally absent on the fibric (acid) peat treatment. (It is interesting to note that in the greenhouse experiments carried out with this peat, alfalfa growth was again non-existent when the peat was fertilized and limed.)

Observations in early June indicated that crested wheatgrass was the dominant grass on treatments where peat was applied (Appendix 4). On the tailing sand, the three grass species were found in equal portions. The July yields were generally very small due to the plants not yet being well established and also because of the low rainfall in May and June (Appendix 3).

Yields in September 1976 varied from 2 to 3 times greater than those of July. Higher rainfall and better establishment of the plants are the important reasons behind these increases. The tailing sand treatment out-yielded the fibric (acid) peat treatment and had slightly greater yields than the mixed-in mesic (stockpiled) peat treatment. The mesic (stockpiled) peat applied as a mulch again had the highest yields. The improved performance of the tailing sand treatment may have resulted from the removal of moisture as a growth limiting factor in the latter part of the summer. Again, in September alfalfa made up a very small proportion of the total yield and was absent on the fibric (acid) peat treatment.

The total season's yields (Plate 6) of the grass-legume crop (also in Table 38) indicated that growth on the fibric (acid)

Plate 6.

The runoff plot on September 8, 1976. Note the vegetative cover and the recording rain gauge (right centre). See Figure 2 for treatment layout.

peat treatment was poorer than the tailing sand (control) treatment. However, growth was improved on the two mesic (stockpiled) peat treatments particularly on the mulch treatment. The largest yield (2.6 tonnes/ha) occurred on the latter treatment. The proportion of alfalfa in the total yields was very small. Several factors have influenced this result including the high nitrogen fertilization which gives the grasses a competitive advantage (Black, 1968; Takyi et al., 1977) and the late summer seeding which resulted in winter kill of alfalfa. The alfalfa was observed to grow better in areas of tailing sand (thus the highest alfalfa yields were in the control treatment and the mixed-in mesic peat treatment) possibly because there was less competition from grasses in these areas or there was a more favourable pH. The fibric (acid) peat treatment was particularly hard on the alfalfa and none survived. Although limed, the initial extremely low pH may have reduced the yields of acid sensitive alfalfa.

The nitrogen content in the plant tops of all treatments was lower at the July cutting than in September, 1976 (Table 39). Fertilization with nitrogen after the July harvest (Table 20) combined with better moisture levels late in the season are the apparent causes of these differences. However, the level of nitrogen in the plants on the tailing sand (control) treatment was high at both harvests due to a high rate of nitrogen fertilization and a (relatively) high proportion of alfalfa in the yield. Plant nitrogen levels on the fibric (acid) peat treatment were the lowest measured and the lack of alfalfa on this treatment may have contributed to

these results. The two mesic (stockpiled) peat treatments had similar levels of total nitrogen in plant matter. Although relatively low in July, the September plant nitrogen levels were very high, a result of nitrogen fertilization following the July harvest and better growing conditions.

Table 39. Total nitrogen content* in the above ground portion of grass-alfalfa crop on the runoff plot treatments at harvests in July and September, 1976.

Treatment	Percent nitrogen in plant material**	
	July harvest	September harvest
Tailing sand (control)	2.7 ± 0.3	3.0 ± 0.1
Fibric (acid) peat, mulch	1.8 ± 0.4	2.8 ± 0.4
Mesic (stockpiled) peat, mulch	1.9 ± 0.1	3.3 ± 0.3
Mesic (atockpiled) peat, mixed-in	2.1 ± 0.6	3.2 ± 0.2

* includes pre-treatment for NO_3 and NO_2.

** mean nitrogen level and standard deviation based on plant samples from four quadrats (50 cm x 50 cm) per treatment in replication 2.

6.3.5 Plot Monitoring Studies

6.3.5.1 Mineral Nitrogen Status

The mineral nitrogen contents of soil samples taken from each of the four treatments of the runoff plot in October 1975,

July 1976 and September 1976 are shown in Tables 40, 41 and 42 respectively. Although most nitrogen fertilizer was applied in the ammonium form, the analyses indicated that in the soil most nitrogen was in the nitrate form. Nitrification, therefore appears to be prevalent regardless of the treatment used. Related to this is the large amount of mineral nitrogen which has been leached downward in the soil profile. By September 1976 more than half of the mineral nitrogen in the profile was at a depth greater than 30 cm. Downward movement of NH_4-N also appears to have occurred on all treatments, likely related to the low CEC of the soil and high permeabilities. McCoy (In: Regier, 1976) also reports rapid leaching of several forms of nitrogen fertilizer through tailing sand.

Mineral nitrogen levels were consistently greater in the mesic (stockpiled) peat treatments than in the fibric (acid) peat treatment. The higher total nitrogen content (Table 19) and better retention of the fertilizer nitrogen by the mesic peat may account for this. Mixing-in the mesic peat appears to have increased the downward movement of nitrogen over that of the mulch application. Mineralization of the mixed-in peat may account for the high levels in the October 1975 and July 1976 samples, while leaching losses may have contributed to the lower level in September 1976.

Table 43 indicates that loss of fertilizer nitrogen in surface runoff was generally insignificant except when rainfall and runoff occur shortly after fertilizer application on tailing sand. Peat applications reduced the amount of runoff (Table 29) which in turn eliminated any runoff loss of nitrogen.

Table 40. Mineral nitrogen content of soil samples from the runoff plot treatments on October 9, 1975.*

Treatment	Depth (cm)	NH_4-N (kg/ha)	NO_3-N (kg/ha)	Total mineral N (kg/ha)
Tailing sand (control)	0 - 15	3	3	6
	15 - 30	1	8	9
	30 - 60	1	23	24
	total	5	34	39 (27)**
Fibric (acid) peat, mulch	0 - 15	2	6	8
	15 - 30	2	16	18
	30 - 60	1	9	10
	total	5	31	36 (25)**
Mesic (stockpiled) peat, mulch	0 - 15	2	11	13
	15 - 30	2	20	22
	30 - 60	3	31	34
	total	7	62	69 (48)**
Mesic (stockpiled) peat, mixed-in	0 - 15	22	7	29
	15 - 30	3	21	24
	30 - 60	11	37	48
	total	36	65	101 (71)**

* samples were taken from replication 2 only (Figure 2).

** value in parentheses is the percent of fertilizer-N applied August 17, 1975 (143 kg/ha) remaining in the top 60 cm of soil on each treatment (see Table 20).

Table 41. Mineral nitrogen content of soil samples from the runoff plot treatments on July 14, 1976.*

Treatments	Depth (cm)	NH_4-N (kg/ha)	NO_3-N (kg/ha)	Total mineral N (kg/ha)
Tailing sand (control)	0 - 7.5	4	10	14
	7.5 - 15	4	7	11
	15 - 30	2	18	20
	30 - 60	2	15	17
	60 - 90	6	28	34
	total	18	78	96
Fibric (acid) peat, mulch	0 - 7.5	7	19	26
	7.5 - 15	5	4	9
	15 - 30	6	8	14
	30 - 60	6	0	6
	60 - 90	3	2	5
	total	27	33	60
Mesic (stockpiled) peat, mulch	0 - 7.5	16	19	35
	7.5 - 15	1	6	7
	15 - 30	2	5	7
	30 - 60	9	3	12
	60 - 90	6	8	14
	total	34	41	75
Mesic (stockpiled) peat, mixed-in	0 - 7.5	17	27	44
	7.5 - 15	2	9	11
	15 - 30	4	17	21
	30 - 60	12	11	23
	60 - 90	11	12	23
	total	46	76	122

* note that on June 9, 1976, 88 kg-N/ha was applied to each treatment.

Table 42. Mineral nitrogen content of soil samples from the runoff plot treatments on September 8, 1976.*

Treatment	Depth (cm)	NH_4-N (kg/ha)	NO_3-N (kg/ha)	Total mineral N (kg/ha)
Tailing sand (control)	0 - 7.5	3	1	4
	7.5 - 15	1	0	1
	15 - 30	6	0	6
	30 - 60	6	2	8
	60 - 90	3	2	5
	total	19	5	24
Fibric (acid) peat, mulch	0 - 7.5	4	2	6
	7.5 - 15	0	3	3
	15 - 30	4	3	7
	30 - 60	5	5	10
	60 - 90	4	7	11
	total	17	20	37
Mesic (stockpiled) peat, mulch	0 - 7.5	3	4	7
	7.5 - 15	2	6	8
	15 - 30	6	8	14
	30 - 60	7	16	23
	60 - 90	6	32	38
	total	24	66	90
Mesic (stockpiled) peat, mixed-in	0 - 7.5	1	6	7
	7.5 - 15	2	3	5
	15 - 30	5	4	9
	30 - 60	6	6	12
	60 - 90	10	10	20
	total	24	29	53

* note that on July 15, 1976, 90 kg-N/ha was applied to all treatments (see Table 20).

Table 43. Mineral nitrogen lost in surface runoff from the runoff plot treatments in 1975.*

Time period	Treatment							
	Tailing sand (control)		Fibric peat mulch		Mesic peat mulch		Mesic peat mixed-in	
	Rep.1	Rep.2	Rep.1	Rep.2	Rep.1	Rep.2	Rep.1	Rep.2
August 17 to August 26	21 (15)	0	0	0	0	0	0	0
August 26 to September 18	-	0	-	0	-	0	-	0
September 18 to October 9	-	0	-	0	-	0	-	0

* kg/ha of mineral nitrogen in runoff water and percent of applied nitrogen lost (in parenthesis).

\- not determined.

Plant top uptake of the applied nitrogen in 1976 varied considerably between treatments, but was generally low (Table 44). Poor growth due to low rainfall and the early stages of plant establishment contributed to very low uptake of nitrogen by the July 1976 harvest. Better conditions in the latter part of the summer resulted in a greater uptake of nitrogen. The tailing sand treatment showed larger uptake than the fibric (acid) peat due to low yields (Table 38) and low plant nitrogen content (Table 39) in the latter treatment. Plants on the mesic (stockpiled) peat treatments showed the greatest nitrogen uptake, with the mulch applied peat application being superior to the mixed-in treatment. Greater yields rather than high plant nitrogen content are responsible for this difference.

The low apparent recovery of applied nitrogen in plant tops and the low amounts remaining in the soil in September, 1976 (Table 42) point to considerable losses of nitrogen by leaching or denitrification or its incorporation into plant roots. Table 45 is a simple accounting of mineral nitrogen for the July 14 to September 8, 1976 period and indicates the relative effectiveness of the plot treatments in utilizing the mineral nitrogen. Large amounts of mineral nitrogen are unaccounted for on all treatments except the mesic (stockpiled) peat mulch application. A large part of the unaccounted nitrogen is assumed (on the basis of Tables 40, 41 and 42) to have been leached from the soil profile. A significant amount of nitrogen would also be tied up in the plant roots.

Table 44. Nitrogen uptake by plant tops at two cuttings and percent of applied nitrogen in plant tops of the runoff plot treatments in 1976.

Treatment	Nitrogen uptake by plants* (kg/ha)			Nitrogen in plant tops as percent of N added**
	July	September	Total	
Tailing sand (control)	11	50	61	34
Fibric (acid) peat, mulch	8	35	43	24
Mesic (stockpiled) peat, mulch	16	58	74	42
Mesic (stockpiled) peat, mixed-in	15	51	66	37

* figures calculated from mean yield multiplied by mean nitrogen content of plants for each treatment at each cutting (see Tables 38 and 39).

** figures based on total nitrogen in plant tops and application of 178 kg-N/ha to all treatments (see Table 20 for details of fertilization).

Table 45. Mineral nitrogen budget on the runoff plot treatments between July 14 and September 8, 1976.

Description	Treatment			
	Tailing sand	Fibric peat mulch	Mesic peat mulch	Mesic peat mixed-in
Soil mineral N July 14*	96	60	75	122
Applied N July 15**	+ 90	+ 90	+ 90	+ 90
Sub-total 1	186	150	165	212
Soil mineral N September 8*	- 24	- 37	- 90	- 53
Sub-total 2	162	113	75	159
Total N in plant tops (kg/ha) September 8	- 50 (27)***	- 35 (23)***	- 58 (35)***	- 51 (24)***
Balance unaccounted	112	78	17	108
Percent of initial N (sub-total 1) unaccounted for	(60)	(52)	(10)	(51)

* kg/ha of mineral N (NH_4 and NO_3-N) in top 90 cm of soil.

** kg-N/ha as NH_4NO_3.

*** values in parentheses are plant uptake as a percent of soil mineral nitrogen on July 15, 1976 (Sub-total 1).

6.3.5.2 Soil pH

Figures 14 to 17 show the soil pH values at different depths on the treatments of the runoff plot. The initial August 14, 1976 values (Table 17) represent the site prior to application of any treatment. The decrease in pH of the 0 - 15 cm layer between August 14 and 26, 1975 shows the effect of fertilization on the poorly buffered tailing sand treatment. On the peat treatments (Figure 15, 16 and 17) this decrease is in response to peat application as well as fertilization.

In 1976, the tailing sand treatment (Figure 14) showed considerable fluctuation in pH levels in each soil layer, with reactions ranging from neutral to strongly alkaline. The deepest layer sampled (60 - 90 cm) generally had the highest pH values. All layers showed a rise in pH during the later part of the summer. Fertilization dropped the pH of the surface 7.5 cm layer from 8.1 on June 10 to 7.1 on July 23, 1976. However, the soils at lower layers (including the 7.5 - 15 cm layer) were not similarly affected. This result suggests that acidifying processes (such as nitrification or absorption of SO_2) are occurring in the surface layer. These observations may also indicate effects of water table fluctuations on the chemical properties of the tailing sand.

The addition of peat, regardless of the type or method of application, had two general effects. First, the pH of the soil surface dropped and remained below pH 7.0 throughout 1976. Second, relative to the tailing sand treatment or the underlying sand layers,

Figure 14. Soil pH values at different depths on the tailing sand (control) treatment of the runoff plot between August 14, 1975 and September 8, 1976. The asterisk (*) indicate fertilizer applied (see Table 20).

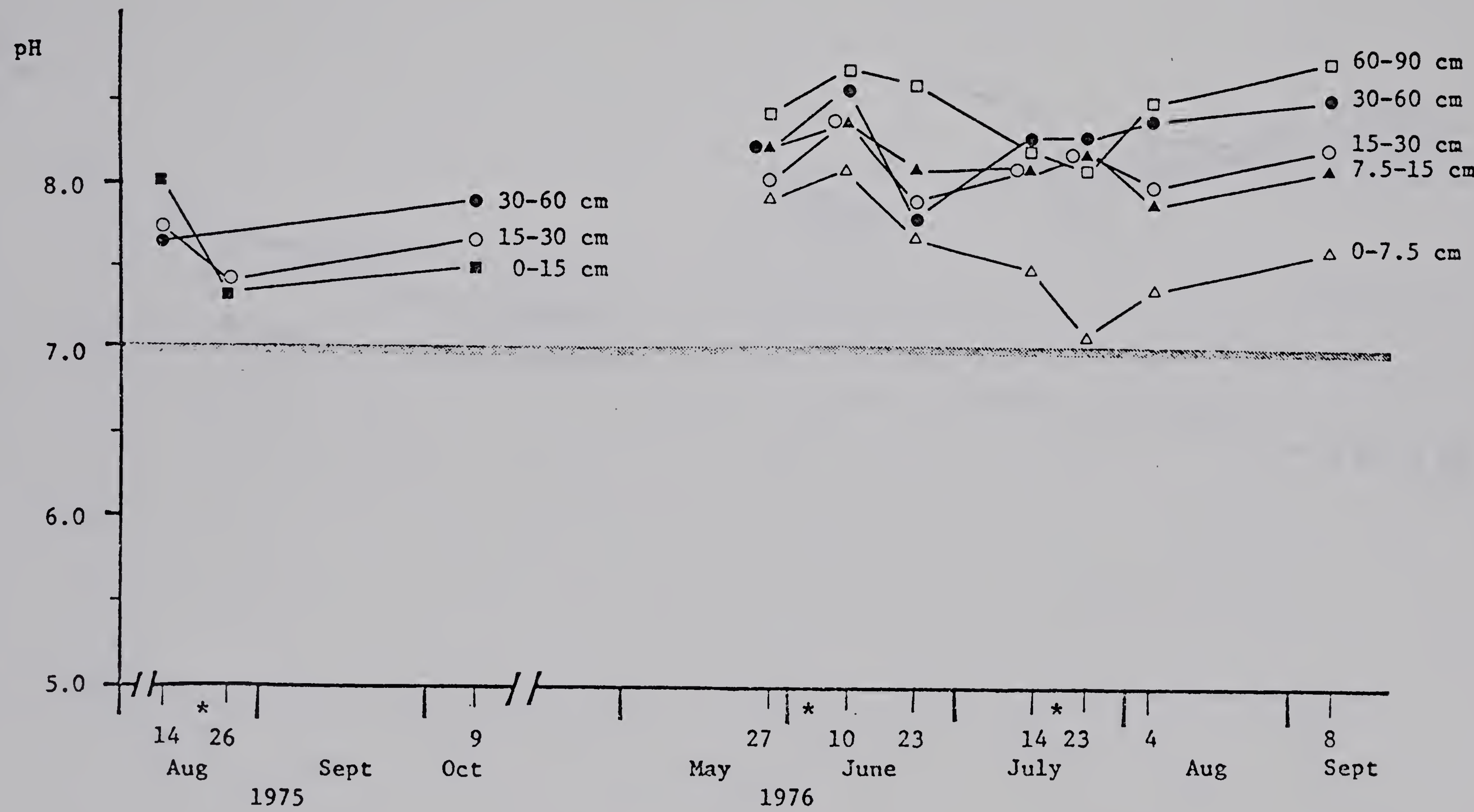


Figure 15. Soil pH at different depths on the fibric (acid) peat, mulch plus lime treatment of the runoff plot between August 14, 1975 and September 8, 1976. The asterisk (*) indicate fertilizer applied (see Table 20).

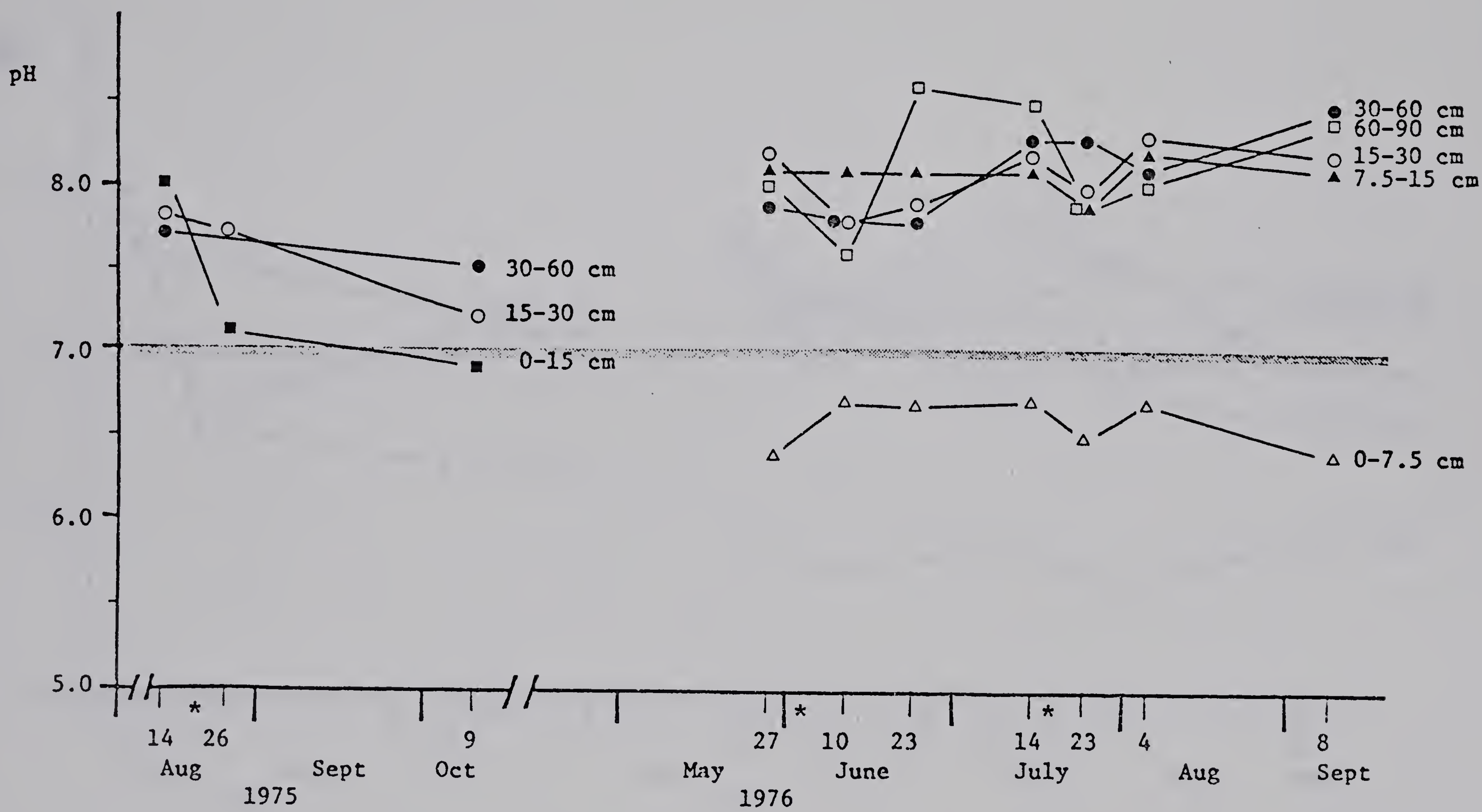


Figure 16. Soil pH at different depths on the mesic (stockpiled) peat, mulch treatment of the runoff plot between August 14, 1975 and September 8, 1976. The asterisk (*) indicate fertilizer applied (see Table 20).

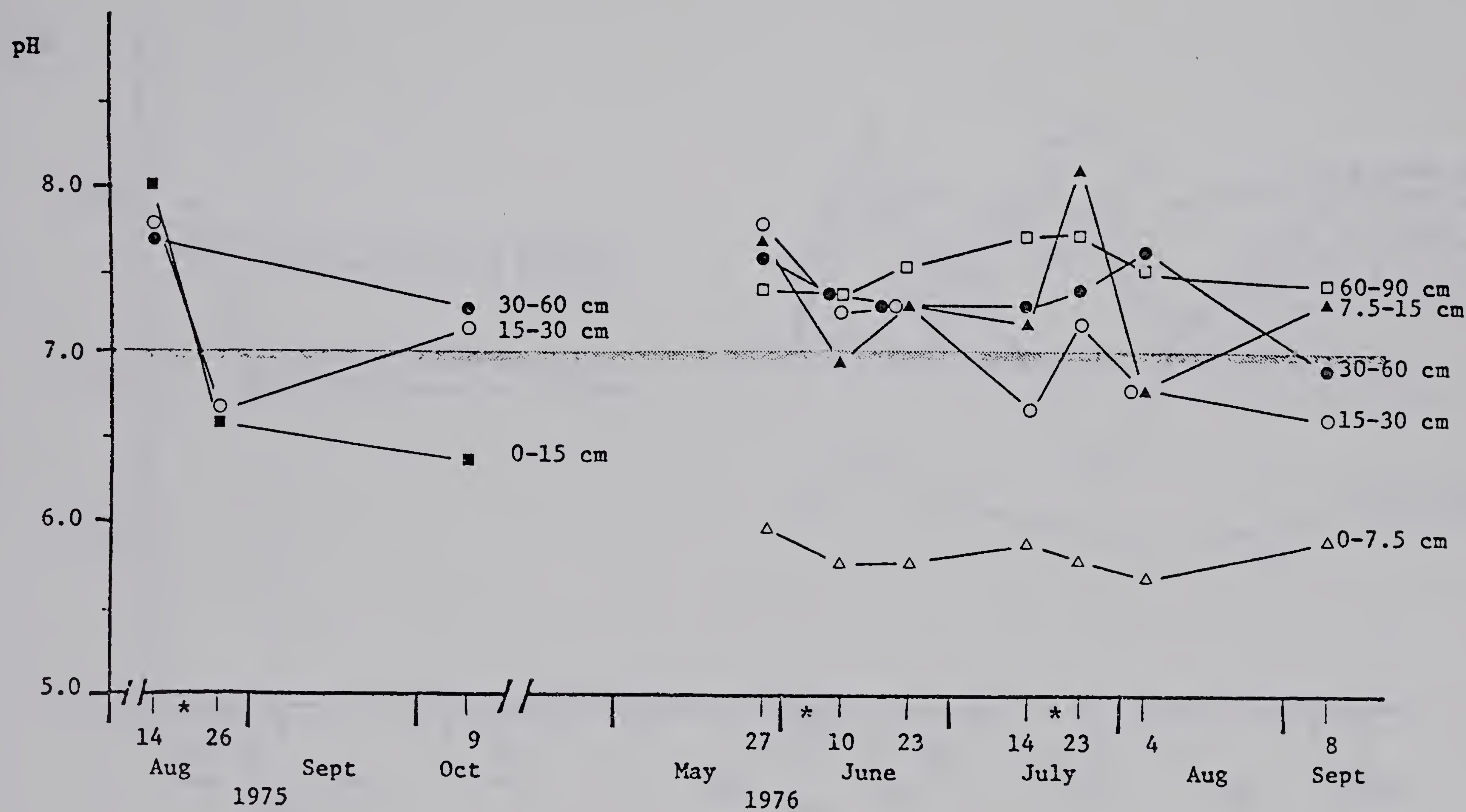
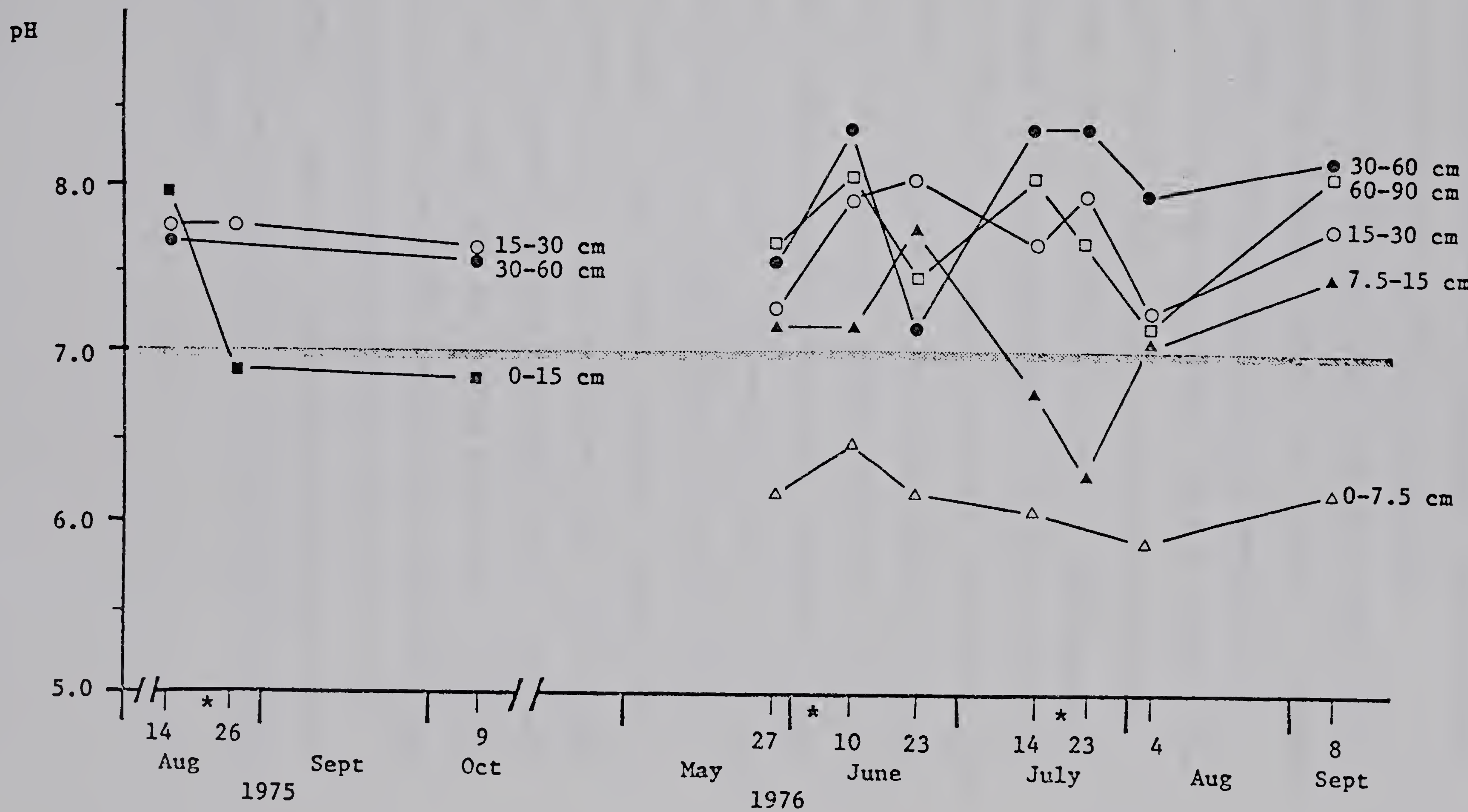


Figure 17. Soil pH at different depths on the mesic (stockpiled) peat, mixed-in treatment on the runoff plot between August 14, 1975 and September 8, 1976. The asterisk (*) indicate fertilizer applied (see Table 20).



the surface peat layer exhibited less fluctuation in pH, reflecting differences in buffering capacities or acid production.

Application of the fibric (acid) peat mulch plus lime at 12.2 tonnes/ha greatly influenced the pH of the surface 7.5 cm layer (Figure 15). However, the deeper soil generally remained at pH levels similar to the tailing sand treatment (mild to strongly alkaline). The pH of the 60 - 90 cm layer (as with the tailing sand treatment) showed large fluctuations. The rate of liming appeared adequate to neutralize the extreme acidity of the peat. Fertilization appears to have had little effect on the pH of the surface layer.

The mesic (stockpiled) peat mulch also resulted in an acid surface 7.5 cm of soil (Figure 16). However, unlike the fibric (acid) peat plus lime treatment, the mesic peat caused a decrease in the pH of soil below the surface layer. The reaction of the 7.5 cm to 90 cm soil layer was reduced from strongly alkaline to mildly alkaline, a level more favourable to plant growth. Leaching of organic acids in the peat is a possible cause of this reduction in pH. Fertilization did not appear to influence the pH of the surface layer. When mesic (stockpiled) peat was mixed into the tailing sand (Figure 17), the surface 7.5 cm layer was less acidic than the mulch application (due to the smaller proportion of peat occurring in the surface of the mixed-in treatment). Deeper soil layers showed considerable fluctuation in pH levels, but were generally less alkaline than the tailing sand (control) treatment.

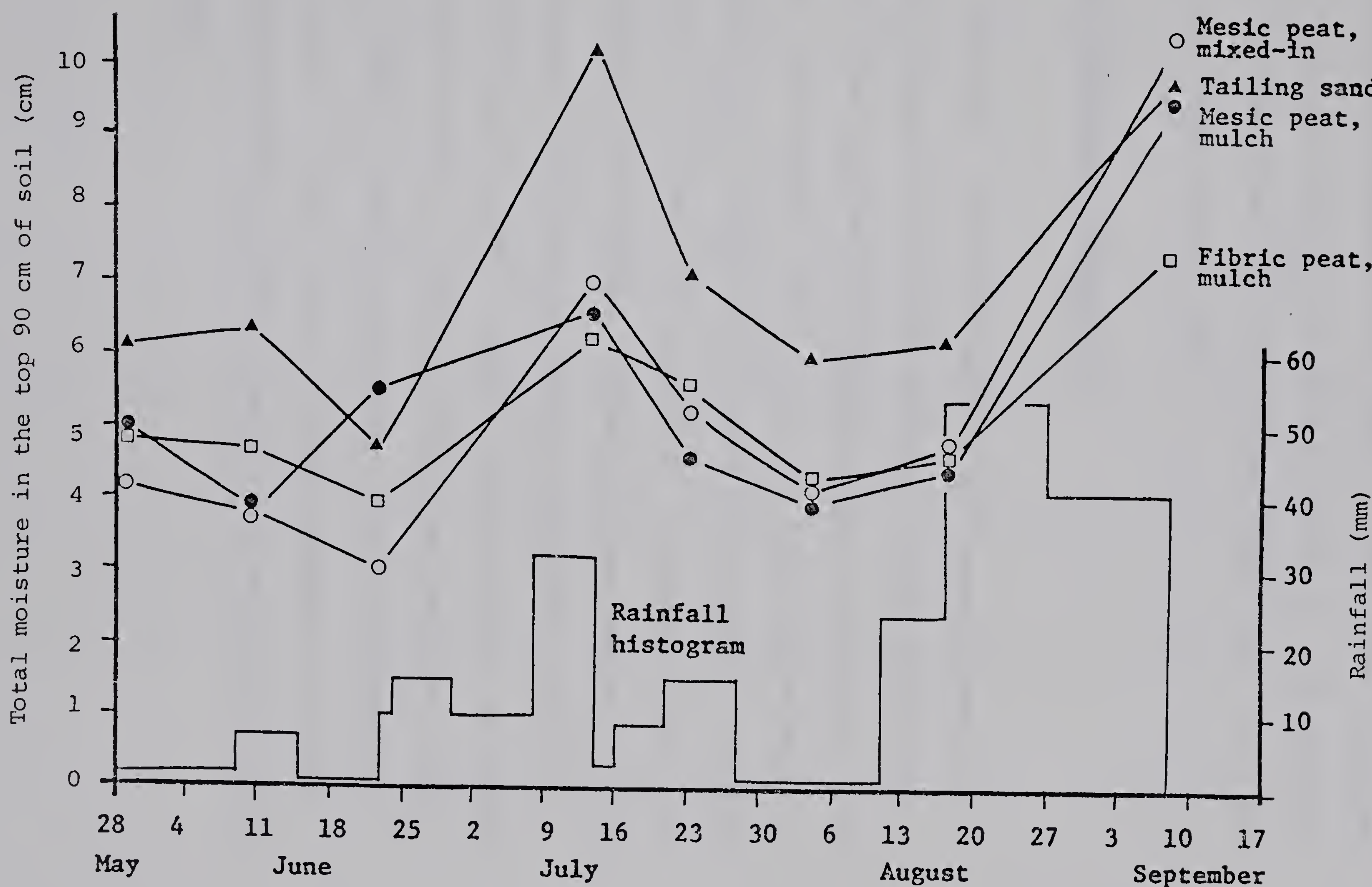
6.3.5.3. Soil Moisture Monitoring

Figure 18 shows the total soil moisture levels of the four treatments of the runoff plot through the 1976 growing season and the rainfall amounts measured at the plot. The fluctuations in soil moisture content generally correspond to both rainfall distribution and quantity.

Application of peat to the tailing sand generally decreased the total soil moisture in the top 90 cm. The increased plant growth (Table 38) with the application of the mesic (stockpiled) peat and therefore greater water loss through transpiration may be the cause of the dry soil conditions on this treatment. However, plant yields on the fibric (acid) peat were lower than on the tailing sand, yet this peat treatment was also drier than the tailing sand. The high moisture storage capacity of the peats combined with high porosity (Table 23) suggests evaporation of the moisture which is retained near the soil surface by the peat. In the tailing sand however, little water is retained near the surface and less is available for evaporation. Feustel and Byers (1936) compared a fibrous, moss peat to a sponge because of its ability to transfer moisture by capillary action to the surface where it is rapidly evaporated. More decomposed peat however was less subject to evaporation water losses.

Observation at the plot site indicated that plants were growing rapidly about July 21, 1976 (up to 10 cm of new growth had appeared on the plots harvested one week earlier). This corresponds to the relatively high moisture content of the soils at this time.

Figure 18. Total moisture in the top 90 cm of the four treatments on the runoff plot through the growing season and the total rainfall in each measurement period at the site in 1976.



However, observation on June 9 and August 11, 1976 indicated that some plants on each treatment were wilting. These dates correspond to the low total soil moisture contents in Figure 18. The tailing sand had 6 cm of water and the peat treatments had about 4 to 5 cm of water in the upper 90 cm of soil.

6.3.5.4 <u>Soil Temperature Monitoring</u>

The results (Table 46) indicate that temperatures in the tailing sand, particularly near the surface, closely relate to air temperatures. Peat applied as a mulch moderates fluctuations in soil temperatures. For example, with a peat mulch high temperatures in August, 1975 at the 5 cm depth were reduced by as much as 10 C while low temperatures in October were as much as 5 C warmer than the corresponding tailing sand readings. Differences were smaller at deeper depths. It would be expected that the peat treatments would be cooler in the spring and growth would be slower to start, as has been found in previous studies of mulching (Kohnke and Werkhoven, 1963; Moody et al., 1963). There did not appear to be any difference in the effectiveness of the two peats. However, mixing-in the mesic peat reduced the moderating effect somewhat over that obtained by the mulch treatment.

Table 46. Soil temperatures at three depths on the runoff plot treatments in 1975, expressed in degrees Celcius.

Date 1975	Time and conditions*	Depth (cm)	Treatment: Tailing sand	Treatment: Fibric peat mulch	Treatment: Mesic peat mulch	Treatment: Mesic peat mixed-in
Aug 26	17:00, sunny	5	23	17	16	19
	soil moist	20	21	16	16	18
	air: 21 C	30	17	15	15	15
	21:00	5	11	16	16	15
	some cloud	20	18	16	16	16
	air: 12 C					
Aug 27	08:00	5	12	14	16	12
	foggy	20	13	15	16	14
	air: 7 C	30	15	16	17	17
	12:00	5	23	15	16	20
	sunny	20	18	14	15	16
	air: 21 C	30	15	15	15	14
	14:00	5	25	17	15	22
	sunny	20	21	15	15	18
	air: 24 C	30	15	15	15	15
	18:00	5	22	16	16	20
	sunny	20	21	16	15	19
	air: 25 C	30	17	15	15	16
	20:30	5	19	16	16	18
	cloudy, windy	20	20	16	16	18
	air: 19 C	30	18	16	15	17
Aug 28	08:00	5	16	15	15	16
	cloudy	20	15	15	15	15
	air: 17 C	30	17	16	15	16
	11:00	5	23	16	16	22
	thin cloud	20	19	15	15	18
	air: 24 C	30	17	15	15	16
Sep 18	10:00, cloudy	5	9	11	-	10
	soil moist	20	9	10	-	10
	air: 9 C	30	11	13	-	12

continued...

...continued

Table 46. Soil temperatures at three depths on the runoff plot treatments in 1975, expressed in degrees Celcius.

Date 1975	Time and conditions*	Depth (cm)	Treatment: Tailing sand	Treatment: Fibric peat mulch	Treatment: Mesic peat mulch	Treatment: Mesic peat mixed-in
Sep 18	14:00	5	12	12	-	14
	cloudy	20	12	12	-	13
	air: 13 C	30	11	13	-	12
	20:00, clear	5	9	12	-	10
	sundown	20	11	13	-	13
	air: 7 C	30	12	13	-	13
Sep 19	09:00	5	5	10	-	6
	foggy	20	6	11	-	8
	air: 2 C	30	10	13	-	12
	15:30	5	16	13	-	17
	sunny	20	16	12	-	15
	air: 19 C	30	10	12	-	11
Oct 9	09:00, cloudy	5	3	8	-	8
	snow and rain	20	3	8	-	6
	air: 2 C	30	5	9	-	8
	12:00	5	5	7	-	7
	cloudy	20	5	7	-	7
	air: 5 C	30	5	9	-	8
	16:30	5	6	8	-	8
	cloudy	20	6	7	-	7
	air: 5 C	30	6	9	-	8

* air temperature (C) in shade 30 cm above tailing sand.

\- indicates temperature not determined.

7.0 GENERAL DISCUSSION

Improvements in moisture conservation, a reduction in erodibility and an increase in soil fertility and plant growth (each an important factor in land reclamation) were obtained by amending tailing sand with peat. However, the effectiveness of the peat additions was influenced by the kind of peat applied, the method by which it was applied and the quantity applied.

The peat additions to tailing sand had a large influence on moisture conservation. Consider the field moisture balance (Baver et al., 1972) where:

$$P - R = E + D + \Delta W$$

in which P is precipitation, R is runoff, E is evaporation (or evapotranspiration), D is drainage, and ΔW is the change in soil water content. In land reclamation, moisture conservation practices involve soil management to reduce runoff, evaporation and percolation losses of water. The objective is to increase the soil water content (W). This is particularly important in a moisture deficit area and moreso when the waste material has a low moisture storage capacity. Plant growth and therefore the success of most reclamation programs is largely dependant on a suitable supply of moisture. Reduction in runoff losses is particularly important because not only is this water unavailable for plant use, but the potential for soil erosion is greatly increased. Several factors explain the need for moisture conservation practices in tailing sand reclamation, including both meteorological and soil characteristics.

The Oil Sands region receives approximately 400 mm of precipitation annually (Table 30) while the average potential evapotranspiration is 470 mm creating a moisture deficit (Laycock, 1964). From data developed by Laycock (1964; see Table 30) a soil in the Oil Sands region with a storage capacity of 13 mm (tailing sand can store 20 mm in the top 100 cm) is over 20 cm deficient in 35 percent of the years. However, if the moisture storage capacity can be increased to 108 mm, the frequency of 20 cm deficiencies is reduced to 12 percent.

Generally the rainfall intensity hazard in Alberta is very low relative to other parts of North America (Toogood, 1963). Data for the Oil Sands area also indicate a low rainfall intensity hazard (Bruce, 1968; see Table 31). However, more recent data (Toogood, 1977) suggests that intensities may actually be higher than the limited meteorological data available indicates. At the same time, the Oil Sands region might be described as runoff and erosion prone if annual precipitation and moisture deficits are considered. The low rainfall limits plant growth, leaving the soil relatively unprotected against erosion from the rainfall which does occur (Satterlund, 1972). This factor would be particularly important in tailing sand reclamation where attempts are made to vegetate large areas of bare sand surfaces. Runoff plot studies (section 6.3) showed that even with relatively short, low intensity rainfall runoff losses and soil erosion did occur.

Evaporation losses also decrease the soil water content and in the Oil Sands region a high (470 mm) evapotranspiration demand (Laycock, 1964) may account for significant losses from bare soil. Aspect influences evaporative demand, with southern exposures (such as

the site of the runoff plot) having a higher demand because of the directness of the sun's radiation. Meteorological conditions of the Oil Sands region therefore necessitate moisture conservation practices to improve plant growth as a primary requirement in land reclamation.

The characteristics of tailing sand increase the need for moisture conservation. Returning to the moisture balance equation, soil properties may influence runoff, drainage and evaporation and through these, the soil water content (Satterlund, 1972; Farmer and Richardson, 1976). Precipitation in excess of soil infiltration rate is lost as runoff. The infiltration rate of tailing sand (although expected to be high because of the sand texture, the rapid hydraulic conductivity and the results of infiltration measurements made using standard ponded water field techniques) was found to be limited by poor wettability (Table 36). Water repellency in soils has generally been related to a high sand-size fraction or hydrophobic substances and is often induced by fire (Savage, 1975). Although the tailing sand contains over 95 percent sand-size particles, the wide range in wettability of samples from various depths (among which the differences in particle-size distribution were small) suggests that some other factor accounts for the water repellency. The fluvial sand from the region also has a similar proportion of sand and yet is highly wettable. Alternatively, the residual hydrocarbon content of the tailing sand (Moschopedis and Mitchell, 1974; Takyi et al., 1977) appears to be the cause. Savage et al. (1975) found aliphatic hydrocarbons (tarry materials derived mainly from undecomposed and partially decomposed plants) contributed to fire-induced water repellency.

Similarly, the remaining hydrocarbons in the tailing sand may create the water repellency. The reduction in the degree of repellency towards the soil surface (Table 36) suggests that factors generally associated with the soil-atmosphere contact zone (such as microbial decomposition, volatilization and solar radiation) may reduce the residual hydrocarbon content with time. The surface 0.5 cm layer of the tailing sand on the runoff plot was observed to be whiter than the underlying grayish tailing sand. Serious soil and water losses occurred from the tailing sand in the runoff plot studies under precipitation rates well below the infiltration rate of the sand as determined by ponded water methods. Debano (1975) also found that under natural rain the water repellency of soil may impede the initial infiltration of water. In contrast, the undisturbed fluvial sand was highly wettable and therefore runoff losses would be expected to be very low. The natural stability of these soils is an indication of low runoff rates. Soil management to increase the infiltration rate of the tailing sand is therefore an important first requirement to increasing the water availability to plants.

The drainage rate of water which has entered the soil also influences quantities of plant available water. Tailing sand has a rapid (46 cm/h) hydraulic conductivity and water quickly drains out of the root zone. The available water storage capacity in a 100 cm root zone of tailing sand is 2 cm, a level which makes the soil very susceptible to drought periods. The fluvial sand is susceptible for similar reasons, too. Therefore soil management to increase the available water storage capacity of tailing sand is a second area for relieving

moisture limitations to plant growth.

Although not specifically investigated, evaporation losses from tailing sand may be significant. Evaporation is greatest from moist surfaces (Baver et al., 1972) and the low wettability of the tailing sand below the surface 1 to 5 mm wettable layer may tend to keep moisture near the surface and susceptible to evaporation. However, once moisture has penetrated the sand, drainage away from the surface would likely be rapid and the evaporation potential reduced. Again, soil management to reduce or maintain low evaporation losses is important to moisture conservation.

As a first step towards increasing infiltration on tailing sand, peat additions were found to increase total porosity from 36 to over 50 percent of the total volume and the air porosity from 6 to over 14 percent as well as maintaining a rapid hydraulic conductivity (over 13 cm/h). The peats also add fiber to the soil surface which reduced splash erosion and impeded surface water flow. These factors resulted in increased infiltration as measured in the field by ponded water (Figure 13) and runoff plot methods (Tables 29 and 33). Fibric peat was found more effective at increasing infiltration presumably because of its initial high porosity and air porosity. Infiltration rate measurements made using the ponded water method show this effect. Air-drying of the peats increased the air porosity and tended to minimize the differences between the fibric and mesic peat. Caution would appear appropriate in the use of humic peat in areas where runoff is a hazard because of possible low permeability. Application of peat as a mulch is necessary to avoid runoff because mixed-in peat results in

exposed tailing sand areas where runoff can start. Runoff amounts on mixed-in peat were similar to those on tailing sand. Surface applied peat tends to dry out which results in increased total porosity and air-porosity. Although the fibric and mesic peats themselves proved somewhat unwettable once air-dried (Table 36), the high fiber content gives these peats a porous surface which allows rapid infiltration. The permeability of sub-surface layers even when high amounts of mesic peat are used would not seriously limit infiltration rates.

The second area for improving moisture conservation relates to available water storage capacity. Additions of mesic peat improved the available moisture retention of tailing sand (Table 24) while fibric peat had little influence. Again, pore-size distribution is an important factor, with more moisture being retained by the more decomposed peat. Air-drying the mesic peat reduced moisture retention therefore mixing in of mesic peat appears the best method of increasing available water storage capacity. The total amount of peat added is also important. For example, if moist mesic peat is mixed at a 1:1 volumetric ratio into tailing sand to a depth of 15 cm the available water in the upper 100 cm is increased from 2 cm to 2.65 cm. However, if this 1:1 mixture is extended to 30 cm, the available moisture is increased to 5.3 cm. Since an available water storage capacity of 10 cm reduces the frequency of moisture deficits to about 12 percent in the Oil Sands region (Laycock, 1964), the mixing in of a high portion of mesic peat into the upper 45 cm would be necessary to greatly reduce periods of moisture stress. On the runoff plot, wilting was observed twice in 1976 on all treatments (including the 1:1 mesic peat-tailing

sand mixture to a depth of 20 cm).

Prevention of evaporation is the third step in conservation. Although not specifically studied or measured several findings point to increased moisture losses if fibric peat is applied to the surface. The combination of relatively low yields (Table 38) and low soil moisture levels (Figure 18) on the fibric peat treatment of the runoff plot indicate losses of water other than through plant use. Feustel and Byers (1936) studied evaporation from sand as influenced by peat type and found that fibric peat increased the rate of evaporation and compared its capillary action to that of a sponge. Allison (1973) suggested mixing peat into the soil to store water away from the surface, while Feustel and Byers (1936) found that decomposed peat, with a broken capillary continuity, tended to insulate the surface against evaporation.

In terms of moisture conservation, the use of mesic peat mixed into the tailing sand to a depth of 45 cm at a volumetric ratio of 1:1 (that is, about 25 cm of peat) and with a thin mulch of the same peat on the surface would greatly improve tailing sand's suitability for revegetation. This would serve to increase infiltration by protecting the surface, reducing runoff velocities, increasing the total pore space and air porosity (especially upon air-drying) and would keep evaporation losses low. By also mixing in the mesic peat, better available water storage would be obtained as the peat is less likely to dry out.

The susceptibility of tailing sand to erosion, particularly by water, is also a serious limitation to reclamation programs in the

Oil Sands. If soil erosion is left unchecked the rate can increase with increasing degree of disturbance and site deterioration (Satterlund, 1972). Therefore, steps to reduce the erosion hazard increase the potential for successful tailing sand reclamation. Additions of peat to tailing sand decreased soil erosion in field studies.

Soil erodibility is one of four factors which influence water erosion, the others being meteorological conditions, topography and vegetation (Ellison, 1944; Smith and Wischmeier, 1962; Baver et al., 1972). This relationship has been expressed as the universal soil-loss equation (Wischmeier and Smith, 1965) and a variation of this equation has been developed and applied to surface mined land in the United States (Farmer and Richardson, 1976). Basically, these same general factors also influence wind erosion (Chepil and Woodruff, 1963).

The erodibility of soil by water is related to its ability to absorb and transmit water and to resist dispersion (Baver et al., 1972). Although tailing sand has a rapid (46 cm/h) hydraulic conductivity, because it has only 6 percent of its total soil volume as air porosity and it is somewhat water repellent, infiltration of water is limited. The ability of tailing sand to resist dispersion is also low because with over 95 percent sand-size particles, the tailings have a single-grain structure and loose consistency. These properties make tailing sand highly water erodible.

The wind erodibility of tailing sand is related to soil moisture and structural conditions (Chepil, 1953; 1956; Can. Dept. of Agric., 1966). Surface moisture tension in tailing sand is often

likely to be above 15 bar because of the rapid drainage. Therefore cohesive forces between soil particles are small (Buckman and Brady, 1971). Aggregation is limited because less than 3 percent of the tailings are silt or clay-size particles. Moschopedis and Mitchell (1974) determined the mean weight diameter of GCOS, Ltd. tailing sand to be 0.292 mm, indicating low aggregation. With 85 percent of the soil separates under 0.84 mm in diameter, there is little resistance to wind erosion. Winds of 24 to 32 km/h have been reported to cause major sand storms on the GCOS, Ltd. tailings dyke (Berry and Klym, 1974).

Two forms of water erosion were observed to act on tailing sand. First, field observations showed that raindrop impact pitted the tailing sand surface, scattering particles into the air, indicating the ease with which the sand disperses (Plate 6). On sloping land this process accounts for a general downslope movement of soil due mainly to the influence of gravity (Bisal, 1960; Lattanzi et al., 1974). Rill erosion was the second form observed, occurring when the infiltration rate of the tailing sand was exceeded and runoff concentrated into channels. Again because of the low resistance to dispersion, the rills in tailing sand can develop into gullies. Soil loss on the tailing sand treatment of the runoff plot (prior to establishment of a vegetative cover) was 50 tonnes/ha for a two month period in 1975. This soil loss was caused mainly by rill erosion as no channels were more than 10 to 15 cm deep.

Application of peat to the surface of tailing sand reduced water erosion by reducing soil splash, runoff and runoff velocity.

The effect is similar to that of a straw mulch (Meyer et al., 1970; Lattanzi et al., 1974). The peat fiber absorbs raindrops, dissipating their kinetic energy. Fibric peat would be expected to be more effective because of its high (over 2/3) fiber content although mesic peat also contains considerable (1/3 to 2/3) fiber (Can. Dept. of Agric., 1974). Humic peats because of their low (less than 10 percent) fiber content may be more susceptible to splash erosion. The surface area covered by fiber is also important. Complete coverage was obtained on the mulch treatments on the runoff plot and no soil loss occurred. However, where the same amount of peat was mixed into the tailing sand approximately half of the surface remained exposed to splash erosion. Small amounts of soil were lost on this treatment. Straw-mulch rates which covered only 25 percent of the surface (approximately 0.5 tonnes/ha of wheat straw) have been found to reduce soil splash losses by one-half while a 61 percent coverage (2.0 tonnes/ha of straw) reduced splash losses to 10 percent of the unprotected soil surface (Luttanzi et al., 1974).

The peat mulch applications greatly reduced water runoff by increasing the infiltration rate and this in turn eliminated soil erosion on the runoff plot. Infiltration measurements made on the runoff plot showed the increase caused by peat addition (Figure 13). Fibric and mesic peats appeared equally effective at reducing erosion as mulches. However, when peat was mixed into the tailing sand, runoff losses of water remained similar to those on the tailing sand treatment although soil losses were much smaller (Table 33). This suggests that the presence of some peat on the surface impeded the rate of surface

runoff as well as reducing splash erosion. Because of the lower runoff velocity, less soil was carried downslope. Studies on the effects of mulch treatments of various soils have pointed to three factors: increased infiltration, decreased soil detachment and reduced runoff velocities, as the method by which water erosion is reduced (Mannering and Meyer, 1963; Meyer et al., 1970; Lattanzi et al., 1974). It appears that peat mulches on tailing sand reduce erosion by influencing all three factors.

The wind erodibility of tailing sand is reduced by the use of peat amendments to increase moisture retention. Mesic peat because of its greater moisture retention should be less susceptible to wind erosion than fibric peat. Observation indicated that peat amendments although not resulting in any soil structural development did produce a rough surface which decreases the erosion hazard (Chepil, 1950). However, once surface applied peat becomes broken and dry its susceptibility to wind erosion would be very high because of the low particle density (Table 13 and Chepil, 1951). Although mixing-in the peat may reduce the possibility of wind erosion losses (Allison, 1972) it likely would not reduce the erodibility of the tailing sand once the surface had dried. Perhaps peat amendments are most useful in controlling wind erosion through their influence on the rapid establishment of a vegetative cover.

The other factors influencing erosion: meteorological conditions, topography and vegetation, should also be briefly discussed.

The meteorological conditions which control plant growth were discussed in relation to moisture conservation, but are equally

important in terms of soil erosion. Poor moisture supplies limit plant growth and increase soil exposure to water and wind erosion. The Oil Sands area is slightly moisture deficient (Laycock, 1964). Although the rainfall intensity hazard for the Oil Sands area is low, relatively low intensity rainfall caused soil erosion on the tailing sand treatment of the runoff plot (Figure 11 and Table 33). Similarly, the wind erosion hazard in the area is low relative to other parts of Alberta (Gov't and Univ. of Alta., 1969). However, because of pre-mining land clearing and design of tailing sand disposal areas, the distance of exposure to winds is greatly increased and this directly affects wind erosion (Chepil and Woodruff, 1963).

The topographic factors of length and degree of slope also influence water erosion. Generally, soil losses have been found to increase from 1.5 (U.S. Environ. Protection Agency, 1976) to 3.0 (Doyle, 1976) times with a doubling of slope length. The scale of water erosion possible is enormous considering that over a two month period in 1975 about 50 tonnes/ha of soil was lost on the relatively bare tailing sand treatment of the 15.2 m long runoff plot. At double this length (approximately equal to the length of the slope between terraces on the tailing sand dyke) soil loss would be predicted to be between 75 and 150 tonnes/ha for the same two month period. Similarly, doubling the percent slope has generally been found to increase soil loss 2.6 times (Doyle, 1976) as the erosive power of runoff is increased by a factor of 4 (U.S. Environ. Protection Agency, 1976). These factors, along with observations (Klym and Berry, 1976; Takyi et al., 1977) indicate that topographic considerations are extremely important in

erosion control. However, unlike natural areas the topographic characteristics of mine wastes can be manipulated. In light of the high erodibility of tailing sand, designing tailing sand wastedumps to reduce erosion potential should take the highest priority in reclamation planning.

Vegetation is the final factor affecting soil erosion by wind or water. The establishment of vegetation greatly increases surface protection against raindrop impact, runoff and winds. Because of the low fertility of tailing sand, amendments which increase and maintain soil fertility and plant growth are an important factor in stabilizing the sand against erosion. The influence of peat amendments in this respect are discussed next.

Improvement of soil fertility and plant growth is the third area where peat additions to tailing sand have an important role in land reclamation. A fertile soil capable of producing good plant growth is necessary if reclamation objectives of erosion control and self-sustained plant growth (Klym and Berry, 1976) are to be met.

Tailing sand has proven to be a poor growth medium mainly because of its low fertility (Massey, 1972; Lesko, 1974; Berry and Klym, 1974; McCoy et al., 1976; Regier, 1976; Takyi et al., 1977). Observation on the field establishment of grasses and legumes in tailing sand indicated that growth was too slow to keep ahead of wind erosion soil losses (Berry and Klym, 1974). Similarly, observations on the runoff plot showed that soil losses from water erosion on the tailing sand treatment bared the roots of many young plants and washed others off the slope.

The tailing sand properties such as the low CEC (10 me/l), the very low organic matter content consisting of residual hydrocarbons (Moschopedis and Mitchell, 1974; Takyi et al., 1977), the neutral to strongly alkaline pH, the low total and available nutrient content, and the poor buffering capacity are related to the over 95 percent sand-size particles as well as the oil extraction process (utilizing sodium hydroxide) which the sand has undergone.

A root zone soil composed of tailing sand also imposes considerable physical limitations on plant growth. These limitations relate to the single-grain structure and loose consistency, the bulk density of 1.4 to 1.5 g/cc, the air porosity of 6 percent, the available water holding capacity of 2 percent (by volume) and the temperature regime which is subjected to considerable fluctuation and extremes.

Growth on tailing sand has generally been found to improve with addition of peat (Massey, 1972; Lesko, 1974; McCoy et al., 1976). Takyi et al. (1977) found peat additions improved root distribution. Results of the present study indicate that the peat amendments affect soil fertility and plant growth on tailing sand in several ways and that the effects vary with the type of peat and the method of application.

The main benefits derived from peat amendments to tailing sand in terms of soil fertility and plant growth are related to the organic matter added. To a lesser extent the nutrient levels in the peat are also important, but these too are related to the organic matter content. The amount of organic matter added in a peat appli-

cation depends on the organic matter content, bulk density and amount of peat applied. Organic matter content depends mainly on how much mineral soil has been mixed into the peat (Allison, 1973), while the bulk density of the peat, influencing the amount of organic matter per unit volume generally increases with decomposition. Application of a 12 cm depth of fibric (acid) peat containing 3 percent ash by weight at a bulk density of 0.05 g/cc supplied 58 tonnes/ha of organic matter to the runoff plot. However, a similar volume of mesic (stockpiled) peat containing 26 percent ash but with a bulk density of 0.21 g/cc supplied 186 tonnes/ha of organic matter. The greater organic matter content per unit volume in mesic peat is important when considering transportation costs for reclamation programs. The total amount (or depth) of peat applied also affects the amount of organic matter added. The amount to be applied should be determined on the basis of the benefits desired as well as the costs of application.

Relative to tailing sand with a CEC of 10 me/l, the peats examined have high exchange capacities, ranging from 40 me/l for fibric peat to 260 me/l for the more decomposed mesic peat. A loam textured mineral soil has an exchange capacity of about 140 me/l (Lucas and Rieke, 1968). The low CEC of tailing sand gives the soil a poor ability to retain and supply plant nutrients. Analysis of soil samples from the runoff plot indicated considerable downward movement of NH_4-N. A combination of the low CEC, light application of peat, heavy fertilization and rapid hydraulic conductivity appears to have caused this leaching. Similarly, McCoy (In: Regier, 1976) reported high leaching losses of applied nitrogen and phosphorous in laboratory studies of

tailing sand. Losses of nutrients to the soil-plant system through leaching necessitates the continual use of fertilizers to sustain growth.

The CEC is related to surface area (Black, 1968) and the humus produced on decomposition of organic matter has a very high surface area (Buckman and Brady, 1971; Allison, 1973). Therefore, the mesic peats have a higher CEC than fibric peats and are better able to increase the nutrient retention and supplying abilities of tailing sand. By increasing the CEC the tailing sand's ability to resist change in pH is improved. This factor is particularly important because of the potential acidification caused by oxidation of fertilizer or atmospheric sulfur dioxide (Takyi et al., 1977). The poor buffering capacity of tailing sand was indicated by the drop in pH from 6.9 to 2.3 with the addition of 5 me H^+/100 cc of soil. Takyi et al. (1977) predicted that mildly alkaline (pH 7.5) tailing sand could become extremely acid (pH 3.3) within ten years through the acidification effects of atmospheric sulfur dioxide. The influence of peat amendments on buffering capacity varies considerably with the type of peat. Additions of 5 me H^+/100 cc of soil caused a drop in the pH of the fibric (Of) peat from 6.1 to 2.9 while the same treatment dropped the pH of the mesic (Om) peat from 6.6 to 4.1. Mesic peat is therefore better able in the long term to keep the soil pH in the range of 6.0 to 7.5 considered best for most crops in Alberta (Alta. Dept. of Agric., undated). The use of extremely acid peat immediately lowers the pH of a tailing sand-peat mixture. The fibric (acid) peat (pH 3.8) when mixed with tailing sand (1:1 by volume)

produced a final pH of 4.3 and poor growth in greenhouse studies. Analysis of exchangeable cations suggested large amounts of exchangeable H^+ in this peat (Table 11). McCoy et al. (1976) found that additions of fibric Sphagnum peat (pH 4.1) to tailing sand significantly decreased yields of barley. However, in the greenhouse studies it was found that application of $CaCO_3$ at 18 tonnes/ha neutralized the acidity and yields of the grass-legume crop were among the greatest obtained. Field monitoring of soil pH showed the buffering effect of a mesic peat amendment to tailing sand during the 1976 growing season. While the surface 7.5 cm of the tailing sand treatment fluctuated between pH 8.1 and 7.1, the surface of the mesic peat mulch treatment ranged from pH 6.0 to 5.7.

The organic matter in peat amendments also influences plant growth through alterations in the tilth, aeration, water availability and temperature regime of tailing sand. Although the root zone bulk density of tailing sand does not approach 1.75 g/cc, the threshold density of sands (Veihmeyer and Hendrickson, 1948), the densities of 1.4 to 1.5 g/cc are moderately high. The 6 percent air porosity (or macro-pore percentage) of tailing sand is less than the minimum 10 to 15 percent suggested by Black (1968) as required for maximum plant growth. Peat additions to tailing sand greatly reduce bulk densities allowing better root penetration. Additions of 25 percent peat (by volume) to tailing sand raised the air porosity to over 14 percent, while greater peat additions produced air porosities of up to 39 percent in laboratory studies. The use of fibric peat results in greater aeration because of the coarse nature of unde-

composed peat. However, perhaps the most important factor here is the total amount of peat applied. Large application when deeply incorporated into the tailing sand will encourage deeper penetration of roots, producing a more stable surface if deep-rooting plants are used. Takyi et al. (1977) studied the effect of mulch versus mixed-in applications of peat on root distribution and found that root distribution was much more uniform where the peat was mixed into the tailing sand. Increases in available water storage capacity can be obtained through the use of peat amendments to relieve growth limitations caused by moisture deficiencies, as was discussed in reference to moisture conservation practices. Soil temperatures were moderated by the application of peat to tailing sand, with mulch applications being more effective than mixed-in peat. The peak temperatures near the soil surface were lowered by several degrees Celcius by peat applications, while the soil also remained warmer longer into the fall under the peat treatment. The reduction in high surface temperatures has been found to contribute to better germination and plant growth (Kohnke and Werkhoven, 1963; Moody et al., 1963; Baver et al., 1972). However, mulched soils tend to be cooler in the spring and seeding operations should take advantage of the improved fall temperatures.

Peat amendments also supply plant nutrients to tailing sand and thereby increase soil fertility and influence plant growth. However, most of the nutrients added are initially in forms which are not readily available to plants. For example the large amount of nitrogen in peat is present mainly in organic forms. Analysis of three peats indicated that an application of 15 cm would supply total

nitrogen at rates of 660 kg N/ha (fibric acid peat), 893 kg N/ha (fibric Of peat), or 1755 kg N/ha (mesic Om peat). However, the ammonium plus nitrate (available) nitrogen levels in these peats were only 1.5, 1.5 and 9.8 kg N/ha, respectively.[1] Similarly, studies of the available phosphorus and potassium in Alberta peats have found these major nutrients are generally deficient (Odynsky, 1934; Walker, 1936). Extractable potassium levels may however, be as high as 135 kg K/ha in a 15 cm depth of fibric peat (McCoy et al., 1976). In the greenhouse studies the growth of a grass-legume crop on tailing sand was not significantly increased by the addition of peat at 50 percent by volume. However, with the application of readily available N, P, K and S, growth was significantly improved on both tailing sand and tailing sand-peat mixes. Studies by McCoy et al. (1976) found that yields of barley grown on tailing sand and tailing sand-peat mixes were mainly related to the use of N, P, and K fertilizer, while the peat had only a small effect on growth. The indication is that the low availability of plant nutrients in tailing sand is not corrected by peat amendments, and this factor remains growth limiting at least in the short term. Similar yield responses to N, P, and K fertilization have been reported for peat soils (Alberta Dept. of Agric., 1970; Van Ryswyk et al., 1974). Peat additions to tailing sand therefore do not replace the initial need for mineral fertilizer applications.

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[1]Footnote: calculations of nitrogen content based on the bulk densities given in Table 13, the total nitrogen contents given in Table 11 and the mineral nitrogen contents given in Table 26.

Most nutrients held in peat are released through decomposition of the organic matter. Application of peat to tailing sand will encourage decomposition through improved aeration drainage and soil temperatures. The use of fertilizers and possibly lime will also promote decomposition (Maclean et al., 1967; Van Dijk et al., 1968; Hamilton and Bernier, 1973; Lindsay et al., 1976) and release of plant nutrients initially unavailable to plants. The rate of decomposition has a very important role in the use of peat amendments, but has not been a topic in the present study.

Other than the major nutrients, plants on tailing sand have been found to respond favourably to application of calcium as $CaCl_2$ (McCoy et al., 1976). Peat amendments supply considerable exchangeable calcium, ranging from 62 to 239 me/100 g in the four peats examined. The more decomposed mesic peats supply the greater quantities. The 12 cm layer of mesic (stockpiled) peat applied to tailing sand on the runoff plot (252 tonnes/ha) supplied exchangeable calcium equivalent to the calcium in 3 tonnes/ha of $CaCO_3$. It should be noted that application of $CaCO_3$ was found to encourage nitrification in all soils used in the greenhouse studies. This increases the potential for losses of applied nitrogen through leaching.

The yields of the grass-legume crop in the greenhouse studies generally indicate that by amending tailing sand with peat and using the proper soil management, yields can almost triple those obtained on tailing sand, regardless of the type of peat used. However, the management inputs required for such yields vary with the type of peat. Most notably, the fibric (acid) peat required large additions of lime

before yields were significantly increased over those of the tailing sand. The mesic (Om) peat had the greatest yield and did not require the addition of lime. The yield measurements made in the field using the vegetation on the runoff plot had less pronounced differences between treatments with the yields on the tailing sand being quite comparable to those on the peat treatments in 1976. Observations and measurement of soil moisture content indicated that the growth on the peat treatments was likely limited by lack of available moisture. For example, wilting was observed twice on all treatments during the growing season. Therefore, the choice of type and amount of peat as well as the soil management pratices for reclamation of tailing sand must consider all growth limiting factors for the particular environment.

8.0 CONCLUSION

This study indicated that peat can be a useful amendment for reclamation of tailing sand wastes produced by the extraction of oil from the Alberta Oil Sands. The tailings, because of their high sand fraction and the processing treatment they have undergone, have a single-grain structure and loose consistency, contain residual hydrocarbons and have a very low fertility.

Investigations showed that because of a low infiltration rate, high hydraulic conductivity, low available water storage capacity and the regional meteorological conditions, plant growth on tailing sand may often be limited by soil moisture.

The high erodibility of tailing sand was confirmed through measurements and observations made on the runoff plot located on the GCOS, Ltd. dyke. This erodibility was related to the high sand fraction resulting in low cohesion between soil praticles and to the water repellency of the sand apparently related to residual hydrocarbons. The degree of water repellency was found to increase with depth suggesting a breakdown of hydrocarbons at the surface although measurements of the actual residue content at different depths were not made. Although the rainfall-intensity hazard for the Oil Sands region is relatively low, runoff plot measurements indicated that the tailing sand was susceptible to erosion even by low intensity rainfall.

Plant growth on tailing sand aside from being limited by moisture and erosion, was restricted by low available nutrient (and

in the long-term, total nutrient) supply and retention as well as physical limitations including high bulk densities, low air porosity and large fluctuations in soil temperatures. The sand has a poor ability to buffer against pH change which may also lead to growth limitations if soil pH moves outside the optimum growth range as might occur due to acidification by oxidation of fertilizer or atmospheric sulfur dioxide.

Comparisons between tailing sand and the existing soil developed on fluvial sand associated with the *Pinus banksiana* (jack pine) community of the region may be useful in reclamation planning. However, differences in the particle-size distribution within the sand fraction, in aeration and particularly between the respective wettabilities and infiltration rates (and therefore erodibility) must be recognized.

The influence of peat amendments on moisture conservation, erodibility and soil fertility and plant growth is related to the type of peat used as well as the method of application and amount applied. Fibric and mesic peats, reflecting different degrees of organic matter decomposition, were studied as amendments to tailing sand. Both types improved infiltration rate, maintained rapid hydraulic conductivities, greatly reduced water erosion in runoff plot studies, reduced soil bulk density, improved soil aeration, improved the soil temperature regime and increased plant growth relative to unamended tailing sand. However, the mesic peat amendments had advantages over the fibric peat in terms of improving available water storage capacity, reducing evaporation and wind

erosion, supplying organic matter, supplying and retaining plant nutrients, and increasing the soil buffering capacity. These effects are related to the greater degree of decomposition of the mesic peat. It was also found that to increase plant growth on tailing sand, peat amendments alone are insufficient and additional treatment is necessary. Fertilization and with some peats, liming was required to increase yields. Results suggest that fewer such inputs are required with mesic peat amendments.

Mulch applications of peat were found more effective than mixed-in peat in controlling water erosion and moderating soil temperatures. However, mixed-in peat retains more available water and encourages deeper rooting. This suggests that in areas where water erosion is a hazard, the optimum field design would be to first mix peat into the tailing sand and then apply a peat mulch over the surface.

Peat application rates should consider all factors which may be growth limiting. In tailing sand reclamation these factors include erosion, soil fertility and soil physical properties, in particular, soil water characteristics. This study indicates that applications of approximately 25 cm of mesic peat may be required to reduce moisture deficits and ensure optimum growth and stabilization of the tailing sand. However, much smaller mulch applications, for example, 12 cm of peat to the surface will greatly reduce soil erosion. Because of its lighter bulk density as well as a lower nutrient content and available water storage capacity, greater amounts of fibric peat would be necessary to obtain the same effect. This is an important

consideration in terms of transportation and reclamation costs.

The differences among peats in characteristics and management requirements when used as amendments to tailing sand necessitates a knowledge of the types and quantities of peat in the mine overburden profile for reclamation planning. A detailed soil survey can provide this information. Understanding the effects of handling and storage on peat properties is also important. In assessing peat characteristics, fiber content (Can. Dept. of Agric., 1974) is perhaps the single most important property to examine as it is related to many peat characteristics. However, botanical composition may be particularly useful in field mapping and identification and chemical properties of pH, total nitrogen content and CEC are important in assessing fertility levels and requirements of lime and fertilizers. Determination of physical properties such as ash content, bulk density and hydraulic conductivity help to describe the exact nature of the peat and its usefulness in tailing sand reclamation programs.

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10.0 APPENDIX 1

Peat Standards

Pore volume, water capacity and air capacity of peats are determined by the AOSERP peat project (VE 5.1 and VE 5.2) (McGill et al., 1976; Lindsay et al., 1976) using techniques developed by Puustjarvi (1968). The method is described below:

1. The bottom of a 2 liter container with perforated base (perforation diameter of 1 mm) is lined with glass wool and the container is then filled with fresh peat without compaction. Large pieces of peat are broken into pieces less than approximately 3 cm in length.

2. The container is covered to prevent evaporation and placed in water to allow saturation of the peat from below. The sample stands for 24 h then the container is removed from the water and drained for 2 h.

3. The wet weight (g/l) of peat is determined then the sample is ovendried (90 C) for 12 h and the dry weight (g/l) of peat is determined.

4. Peat standards are calculated as described below:

   a) $$\text{Pore volume (\%)} = \left[1000 - \frac{\text{Dry weight}}{\text{Real specific gravity of peat}}\right] \frac{1}{10}$$

   b) $$\text{Water capacity (\%)} = (\text{Wet weight} - \text{Dry weight}) \frac{1}{10}$$

   c) Air capacity (%) = Pore volume - Water capacity

   Note that the bulk density of the peat at the water capacity moisture percent may also be determined:

   $$\text{Bulk density (g/cc)} = \left[\frac{\text{Dry weight}}{\text{Wet volume}}\right] \frac{1}{1000}$$

11.0 APPENDIX 2

Percentage of bromegrass and alfalfa seeds germinating on various soil materials under three treatments in the greenhouse experiment (section 5.2.0).

Soil material	Treatment	Percent germination*	
		bromegrass	alfalfa
Fibric (Of) peat	control	93	87
	fertilized	93	93
	fertilized + limed	80	93
Mesic (Om) peat	control	87	93
	fertilized	87	87
	fertilized + limed	87	93
Fibric (acid) peat	control	100	53
	fertilized	93	80
	fertilized + limed	87	93
Tailing sand	control	73	87
	fertilized	73	80
	fertilized + limed	80	67
Tailing sand + fibric (Of) peat	control	100	87
	fertilized	93	87
	fertilized + limed	93	87
Tailing sand + mesic (Om) peat	control	80	93
	fertilized	87	87
	fertilized + limed	93	87
Tailing sand + fibric (acid) peat	control	93	93
	fertilized	93	80
	fertilized + limed	87	87

* percent germination is the mean of three replications and based on 15 seeds per species in each pot.

12.0 APPENDIX 3

A. Rainfall (mm) between May 1 and October 9, 1975 from the GCOS, Ltd. "Top Gate" station, obtained courtesy of GCOS, Ltd.

Day	May	June	July	August	September	October
1	0	0	0	0	0	0
2	0	0	0	4.3	19.0	0
3	0.5	5.1	0	0.5	7.0	0
4	0	0	0	27.9	0	0
5	0	2.5	0	0	6.0	0
6	0	5.1	0	0	0	4.0
7	0	3.8	Tr	0	0	8.0
8	0	11.4	0	0	0	0
9	0	3.8	0	0	3.0	0
10	0	0	0	0	Tr	-
11	0	6.6	0	1.0	0	-
12	0	0.3	Tr	6.4	0	-
13	0	0	74.9	0	0	-
14	0	1.8	8.6	0.5	0	-
15	4.6	4.6	0	0	3.0	-
16	0.3	0.5	29.2	0	8.0	-
17	0	0	1.8	0	2.0	-
18	1.0	1.8	0	Tr	0	-
19	0	0	Tr	0	0	-
20	0	0.3	0	4.6	0	-
21	0	0	0	0	0	-
22	0.3	0.3	4.1	9.1	0	-
23	11.4	4.8	0	3.1	0	-
24	5.1	1.0	0	0.8	2.0	-
25	5.3	3.3	2.8	0	4.0	-
26	0	9.4	Tr	0	Tr	-
27	0	1.3	0	0	0	-
28	0	17.8	0	14.7	13.0	-
29	0	0	0	18.3	0	-
30	0	0	Tr	6.6	0	-
31	0	-	0	0	-	-
Monthly total	28.5	85.5	121.4	97.8	67.0	-

Tr = trace amount.

B. Rainfall (mm) between May 1 and September 30, 1976 from the GCOS, Ltd. "Top Gate" station, obtained courtesy of GCOS, Ltd.

Day	May	June	July	August	September
1	0	2.0	0	2.8	5.1
2	0	0	0	0.5	0
3	0	0	0	0.3	0
4	0	0	0	0	1.5
5	0	3.8	0	0	0
6	0	0	6.3	0.6	39.9
7	0	Tr	12.4	0	Tr
8	0	0	3.0	0	0
9	0	8.9	1.3	0	0
10	0	5.9	0	0.5	0
11	3.6	0	2.0	0	0
12	3.6	0.5	3.0	0	0
13	0	0	1.9	31.2	0
14	Tr	2.0	0	0	0
15	0	0	1.9	0	0
16	0	0	4.3	0	0
17	0.4	0	0	Tr	0
18	0.8	0	0	0	0
19	0	0	0	0	0
20	0	0	5.3	0	0
21	0	0	2.5	0	0
22	1.5	0	0	0	0
23	0	15.3	4.6	0	0
24	0	6.1	0	0	0
25	0.6	1.8	0.5	Tr	0
26	0	1.0	3.0	36.8	0
27	0.3	0	5.3	0	0
28	0	0	Tr	1.3	Tr
29	0	0	0.6	0.3	0
30	1.5	0	0	1.3	0
31	0	-	0	0	-
Monthly total	12.3	47.3	57.9	75.6	46.5

Tr = trace amount.

13.0 APPENDIX 4

Plant composition on the runoff plot treatments on June 9, 1976.

Treatment	Percent of total plants*				Total plants per m^2	Percent coverage**
	bromegrass	crested wheatgrass	creeping red fescue	alfalfa		
Tailing sand	28	30	28	14	284	23 ± 8
Fibric (acid) peat, mulch	27	59	14	0	204	47 ± 21
Mesic (stockpiled) peat, mulch	22	66	5	7	236	58 ± 8
Mesic (stockpiled) peat, mixed-in	28	60	2	10	200	57 ± 6

* mean of three, 50 cm by 50 cm quadrats per treatment.

** mean and standard deviation based on three, 50 cm by 50 cm quadrats per treatment on replication 2 only.